SIMULATION OF A BEEF PRODUCTION SYSTEM IN THE MOIST SUBTROPICS

Howard Jeffery

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While most scientific projects require collaboration this is particularly true for modelling projects. Some specific contributions of other workers have been mentioned in the Acknowledgements. However, the major contributions made by others were made when they pointed out the shortcomings of a view I was presenting or advanced a different point of view. It is impossible to indicate the importance of those contacts, although, the thesis would be very much worse without them. Nonetheless, the model described in this thesis was written entirely by myself and the conclusions based on its operation are my own.

..........B.Jeffery..

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SUMMARY

A simulation model of a beef farm on the far north coast of NSW was constructed and validated. The final version was used to examine the consequences of altering time of calving, stocking rate and rate of nitrogen fertilization over a three-year period.

The model was composed of three major sections: a climate generator, a pasture generator and an animal sub-model. The climate generator reproduced what appeared to be realistic rainfall patterns using a first-order Markov process to generate rainfall conditional on whether rain fell on the previous day or not. The probabilities of rain falling were derived from historical data. The mean daily temperature was also generated and the combination of mean temperature, day of the year and whether rain fell or not was used to predict pan evaporation - this equation was developed from data obtained in the region under study. Actual evapotranspiration was calculated on a daily basis, but used a method which considered the evaporative demand pattern within a day. When this method was incorporated with the soil moisture routine good agreement was obtained between the model and some Canberra data.

The pasture was taken to be composed of four competing pasture species : _Axonopus affinis_, _Paspalum dilatatum_, _Pennisetum clandestinum_ and _Trifolium repens_. Competition between these species depended on the growth rate of each species, the fraction of ground cover it occupied and the nitrogen content of the soil. Growth rate was defined to be a function of available pasture, evaporation ratio (actual/potential evapotranspiration), temperature, and the phosphorus and nitrogen contents of the soil. Provision was incorporated in the model for the application of either phosphorus or nitrogen fertilizers.

Within each species, five or six pools were defined; four pools contained green dry-matter, pool 5 contained dead dry-matter and in the case of the first two species mentioned

a sixth pool was considered to contain inflorescences and their associated stems. Growth rate was calculated on a daily basis and new material added to pool 1. Each day a transfer of material from pool 1 to 2, 2 to 3 ... 4 to 5 occurred depending on the pasture senescence rate. The rate of transfer out of pool 5 depended on the pasture decay rate.

Animals "grazing" the pasture selected a diet which depended on the amount of material in the various pasture pools. There was a positive selection for material in pool 1 over pool 2, pool 2 over pool 3, ... and a minor preference for clover over grasses. Each pool-species combination had a defined digestibility and fibre content. Feed intake was limited by either the energy demands of the animal being satisfied or the maximum amount of "bulk" being consumed. Provision was made for the consumption of either grain or hay.

Where possible, utilization of feed followed the method defined by the Agricultural Research Council of the UK. An exception to this was in the allocation of nutrients within the animal for liveweight gain (positive or negative) in the lactating cow. A method was developed which allowed a drop in milk production when a poor feed was fed, a permanent drop in the ability to produce milk if a poor feed was fed for long periods, an increase in milk production if a cow's diet changed from poor to good feed and either a positive or negative liveweight change at any stage of lactation. This routine is regarded as being a good prototype for more refined milk production models.

The complete model was "validated" against data from a comprehensive experiment conducted in the region under study. Validation consisted of a three-stage process using two separate parts of the data and, finally, all the data. It became clear that the magnitude of the "natural" variability in the data would prevent very good agreement between model and data, even if the structure of the model were perfect. The consequences of the high variability and the subjective and difficult nature of validation are discussed in some detail.

Finally, the model was used to investigate the economics and the sum of the direct and indirect energy costs of 27 treatments arranged in a 3^3 factorial design (time of calving x level of nitrogen fertilizer x stocking rate). The scale of this simulated experiment was such that it could never be conducted physically as 150 breeding cows were assigned to each treatment. It was concluded from this system test that on both economic and energy cost bases, nitrogen fertilizer had no place in a breeding system on the far north coast of NSW. Time of calving had little influence, though an advantage from late calving may occur. Predictably, stocking rate had a large influence on the economic and the energy cost per hectare.

In the final chapter of the thesis, the study is reviewed and several important problems in agricultural management simulation studies are discussed. A new approach to the simulation of pasture growth is suggested which would obviate some of the problems encountered in this study. The difficulty and subjectivity of validation is once more stressed.

Chapter 1

INTRODUCTION

Simulation modelling is a relatively new technique to be applied to agricultural management problems. It is seen as having great potential in management studies (Arcus 1963; Morley 1968) and sometimes may be the only feasible approach. This thesis describes the construction and validation of and, finally, experimentation with a model of a beef farm on the far north coast of NSW.

The subject was chosen for two reasons. First, I had just spent a little over four years on the north coast at the Wollongbar Agricultural Research Station and thus had some appreciation of the behaviour of a grazing system in that environment. It was hoped that this knowledge would reduce the number of frangible assumptions incorporated in the model. The second reason was that many advocates of systems analysis (Spedding 1970; Van Dyne 1970, amongst numerous others) have seen one of the applications of simulation being the exploration of potentially important fields in which few data have been collected. Beef systems on the north coast fell into such a category.

Dairy production has been the traditional and major industry on the north coast since the late 19-th century and a considerable amount of research has been conducted at the Wollongbar Agricultural Research Station on this industry. In the early 1950s the number of dairy farms on the north coast began to decline (Standen 1969). Data extracted from Standen's report indicate an annual rate of decrease in numbers of dairy cattle of about 2.8 per cent and an annual increase in beef cattle of about 7.1 per cent over the period 1958-1967. In 1966 there were more beef cattle than dairy cattle in the north coast statistical division, yet at the time of commencement of this study only one experiment (Mears 1973) had begun at the Wollongbar Agricultural Research Station which explicitly examined beef cattle systems.

Definitions

The term "system" has a connotation to most people, yet, it is doubtful whether the sense in which it is used in the phrase "systems analysis" can be concisely defined. I know of no succinct definition of this term which captures the philosophy of approach the phrase implies to me, nor can I derive one. Dale (1970) observed that systems analysis has rarely been defined when introduced into ecological studies.

Anderson (1974) distinguished between systems analysis and simulation modelling, arguing that the former involves a broader and more philosophical approach. The same distinction will be made in this thesis and the phrases systems analysis, systems approach and holistic view will be used interchangeably. The term "simulation modelling" will be used in connection with the techniques of building a computer model of a system.

No formal literature review has been attempted in this thesis. This decision was made as several recent and comprehensive reviews on the application of systems analysis and simulation modelling to biological fields have been published (Dale 1970; Dent and Anderson 1971; Benyon 1972; Anderson 1974). Three recent publications also provide examples of a variety of applications of simulation modelling to agricultural systems. These publications are the proceedings of a symposium on the use of models in agricultural and biological research held at Hurley in the UK in 1969 and published in 1970, an almost 400 page book edited by Dent and Anderson and published in 1971 and the symposium on systems analysis held in Canberra and published in the Proceedings of the Australian Society of Animal Production (1972).

The descriptions of the various sub-models provide brief reviews of the literature. Any attempt to make these reviews comprehensive would have added tens, if not hundreds, of pages to the thesis and years to the compilation of it. Thus, the references mentioned are considered to include some of the important ones in the particular fields, but the list is by no means exhaustive.

Complexity

The most consistent feature of expository articles on simulation modelling is the stern warning that undue complexity should not be included in the model (Dent and Anderson 1971; Armstrong 1972; Garfinkel et al. 1972). The next most consistent feature has been the failure to describe how "undue" complexity can be recognised. Extreme examples of degrees of complexity that may be inappropriate are easy to generate and denigrate. In practice the problems are not as clear-cut and the decision will be very much a subjective one. In this context it is probably wise at the outset to accept, as have many others (Garfinkel et al. 1972; Anderson 1974), that simulation modelling is better regarded as an art than as a science. Ironically, simulation modelling usually involves what would be often regarded as the epitome of technology - the electronic computer.

De Wit (1970) saw the problem of complexity in terms of "levels of knowledge" each with its associated "relaxation time". Although no rigorous definition of relaxation time was offered by de Wit, the point of view he was advancing was fairly clear. An example was given of a stomate having a relaxation time of seconds whereas it would take years for a damaged forest to recover. It was thus implied by de Wit that a model of forest regeneration would be unduly complex if it was also concerned with stomate movement. The concept of relaxation times is useful in that it provides a qualitative basis for the estimation of complexity. However, even if relaxation times can be agreed upon the decision as to whether the relaxation times are too far apart will still be subjective.

In the model described in the following pages a larger range of biological features has been incorporated than exist in several other contemporary models (Freer et al. 1970; Wright 1970; McKinney 1972; Vickery and Hedges 1972). The degree of biological complexity being intermediate between that of the above models and the IBP model ELM, parts of which were described by Anway (1973) and Sauer (1973).

Several of the variables in the model are stochastic. It was thought that to ignore between-year variability in rainfall and temperature would result in the conclusions being based on unacceptably unreal conditions; rainfall and temperature have thus been included as stochastic variables. Other variables treated as stochastic are the number of cows becoming pregnant during mating and the number of male and female calves born. The major reason for adding a stochastic element to these variables was to allow an examination of some of the consequences of chance variation in a whole-farm context, particularly when herd numbers are small. Although the long-term economic effects of chance variation would be small, it is conceivable that chance variation could have considerable impact over a short period.

The model was written as a series of difference equations and used a one-day time step. One reason for preferring this value to a longer one (which would have used less computer time) was that the estimation of actual evapotranspiration involves a consideration of the daily pattern of evaporative demand. A one-day time step was also the shortest that could be reasonably considered as the rainfall and temperature records available to me were recorded daily.

The Modelling Team

The literature on simulation modelling is showing evidence of grouping into those who consider a mathematically erudite person an essential member of any team and those who regard mathematical skills as of secondary importance. Mathematicians and biometricians such as Radford (1967, 1970), Benyon (1972) and Garfinkel et al. (1972) appear to regard it as axiomatic that any significant modelling attempt will be undertaken by a team, one of whom has received some specialized mathematical (including statistical) training. On the other hand, biologists have expressed a different point of view. De Wit (1970) described the strategy of model building and stated that the biologist, who is to be the modeller, can not "expect much help from the mathematician because there are in fact no mathematical problems involved". Morley (1972) presented a similar attitude, whereas economists (Dent and Anderson 1971) appear to adopt an intermediate position.

General agreement on the desirable composition of a modelling team will probably never be reached. However, almost invariably the modeller will need help and guidance from workers in other disciplines (Morley 1972).

A Final Warning

Before commencing the detailed description of the model several preliminaries remain. It is traditional for models to receive a name that is in some way descriptive or is formed from an acrostic. An example of the former is the model of Freer and Armstrong, termed HAGGIS, which simulates ruminal activity. An example of the latter is this model which derives its name, SCREW, from the following:

Simulation of a
Cattle
Raising
Enterprise
With a digital computer.

The less charitable may also regard this term as being descriptive.

A Fortranesque language has been used to present all equations and short segments of programming in the text. A brief acquaintance with Fortran should be sufficient to allow the equations to be understood. The reader to whom Fortran is unfamiliar is directed to the succinct description (6 pages) of Fortran programming given by Watt (1968). In the model, most of the variables belong to arrays. However, unless some specific point is being illustrated, subscripts are not presented in the text version of the programming. The variables are usually given the same names as are used in the model, but, in the interests of brevity, this rule has not always been applied.

The model is composed of three major sub-models; the climate generator, the pasture sub-model and the animal sub-model. Several trends are evident in this sequence. The data available for analysis and synthesis and the precision with which they have been obtained decrease from climate to plant to animal. Consequently, the representation of the climate obtained from the climate generator is more likely to be a faithful reproduction than is the portrayal of feed utilization contained in the animal sub-model. A further consequence is that the assumptions within these sub-models become more tenuous as the above progression is followed.

Dillon (1971) promulgated three Laws of Simulation. They bear repeating.

(i) Simulation, like statistics, cannot prove anything,
(ii) Simulation, like statistics, can nearly prove anything,
(iii) Once started, simulation will continue until available funds are exhausted.

Anderson (1974) complemented these laws with three hypotheses

(i) Every simulation study has its trenchant critics,
(ii) The more aggregative the simulation, the more liable it is to criticism,
(iii) Study through simulation always absorbs more resources than anticipated *a priori*.

Whilst these laws and hypotheses were presented partly in jest, they contain significant thoughts which should be kept in mind whenever undertaking a simulation study - or reading the description of one.

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Chapter 2

THE CLIMATE GENERATOR

Two difficult decisions have to be made by the builder of a simulation model which includes climatic input. The first concerns the choice of variables to be included in the model; the second decision is whether the values used will be a sample of real data or generated data.

Because many climatic variables are highly correlated, e.g. temperature and solar radiation, the exclusion of one variable from the model may have little effect on the output. The exclusion of variables simplifies the model but will reduce the size of the parameter space to which the model can be applied, e.g. a model of plant growth based on soil moisture may give good predictions in say, an arid environment, but it could not be expected to yield good predictions in a cool temperate environment where temperature and solar radiation are more likely to limit plant growth. The final decision about which variables are to remain in the model is a compromise. In the absence of any developed theory on the subject, the decision is a subjective one though factors such as the time step (integration interval) being used, the theoretical significance of the variables and the degree of correlation between variables should be borne in mind when making the decision.

Climatic variables are often called the "driving forces" of ecosystem models. This is a reflection of our attributing primary importance to these variables, particularly solar radiation, in "powering" the earth's biosphere. Historical climatic data are often used to define the "climate" of simulation runs, partly because of the fundamental nature of environmental variables and partly because of problems of estimation and sampling. The arguments for or against the use of historical data are, in principle, applicable to all environmental variables. In practice, the variable which causes the major difficulty is rainfall, so it has been used as the "case type" in the following discussion.

The majority of agricultural models have used historical data to provide the rainfall input (Freer et al. 1970; Wright 1970; McKinney 1972; Vickery and Hedges 1972; Smith and Williams 1973). Only rarely have models (Trebeck 1972; F.H.W. Morley pers. comm.) generated the rainfall data, although Phillips (1971) argued strongly that this approach was better.

Phillips' advanced two arguments. First, an historical sample of real data cannot give a complete coverage of all possible values, hence, not all theoretically possible values have a finite chance of occurring in the model. This, he argues, makes the variable, which is theoretically continuous, decrete in practice. The second argument advanced was that a certain lack of smoothness will almost certainly occur in the historical data, e.g. there maybe a greater probability of receiving rain in say, the 30-35mm range than the 25-30mm range although modal rainfall may be 10mm. Phillips regards this as being due to a fluctuation in the sampling rather than a lack of smoothness in the underlying process.

The arguments of Phillips are technically correct but their relevance may be questioned. Both arguments are concerned with the extreme values of distributions. At these high levels of rainfall, field capacity is likely whether the correct or a somewhat biassed estimate of rainfall is used. As the fate of run-off rainfall is generally outside the scope of agricultural management models it is therefore irrelevant whether run-off is 20 or 25mm.

An advantage of using data obtained from a rainfall generator is that the sequence of data is controlled by the random number initiator (seed) of the computer's random number generator. Consequently, at relatively low cost a large number of different yearly sequences of rainfall can be generated, each sequence being tied to a particular initiating seed. Thus, the model can be run over say, four years of below average rainfall all with wet springs by the use of a few simple Fortran statements such as

```
DO 100 NYEAR = 1,4
NSEED = NSTORE(NYEAR)
CALL RANSET(NSEED)
```

where NSTORE holds the already determined appropriate seed values of the random number generator. In theory, the same approach could be used with sets of historical data, although storing and manipulating tens of years climatic data would probably introduce some practical data retrieval problems.

If an agricultural management simulation model is to be used in decision-making and has stochastic rainfall input, then the decision must be based on an adequate sampling of years which include variations in the totals and distributions of rainfall. One way of meeting these objectives is for the input data to be a large random sample, e.g. 25 years. Such a sample must be long enough to avoid any undue influence from wet or dry "cycles" within it. Alternatively, the modeller may select years of good, average and poor rainfall and weight the model outputs according to the probability of occurence of good, average and poor years. Rather than ranking years as good, average or poor, the years may be ranked according to the pattern of rainfall within them. For example, the years may be rated as "wet spring" or "dry summer" years and, as in the previous case, the outputs weighted according to the probability of occurence of the so-defined years. Although the last method is similar in principle to the definition of the years as good, average or poor, it has the advantage that the type of year chosen can be of direct relevance to the agricultural system being tested, e.g. years defined as "dry spring" may well be chosen if the associated model is concerned with cereal cropping. The latter two methods, which do not involve random sampling, and may only involve a two or three year run, will use considerably less computer time than the first method which may involve a run of more than 25 years.

The rainfall data incorporated into a run of the model can either be a sample of historical data or may be generated within the model. Using historical data is straightforward and no assumptions need be made about the rainfall probability distribution. On the other hand, it may, but need not, use large amounts of computer storage, and it will probably introduce some practical data retrieval difficulties. If rainfall input is obtained from a rainfall generator, then little computer storage is needed and, as demonstrated above, the rainfall pattern can be easily manipulated. Although not compelling, Phillips' arguments also provide reasons why a rainfall generator may be preferred. It would be fairly simple to apply a rainfall generator to a neighbouring region which experiences a similar climatic pattern. If few rainfall records exist for this neighbouring region, then the development and "extrapolation" of the generator may be preferable to the use of the relatively few, perhaps atypical, records. I can see no simple solution to the question of whether one should or should not use historical rainfall data. In fact, two of the dominant reasons for building a climate generator in this model were strongly personal ones : (i) the building of the generator represented a challenge, and (ii) it appeared to me to be a more elegant approach.

Mean daily temperature, daily rainfall and daylength are the environmental variables generated in the model. Temperature and rainfall estimates are stochastic. The three generated variables, together with the date, allow calculation of potential and actual evapotranspiration and the soil moisture budget. The majority of these calculations are performed in subroutine CLISIM, although it needs the associated function subprograms ANORM and RAINRV. A flowchart of this process is presented in Figure 2.1.

Rainfall Generation

Rain is often associated with atmospheric low pressure systems which frequently influence a region for several days. Consequently the probability of rain occurring on a particular day is increased if rain fell on the previous day. Thus, rainfall data exhibit a high degree of autocorrelation and random sampling from a simple probability distribution will not accurately reproduce rainfall patterns.

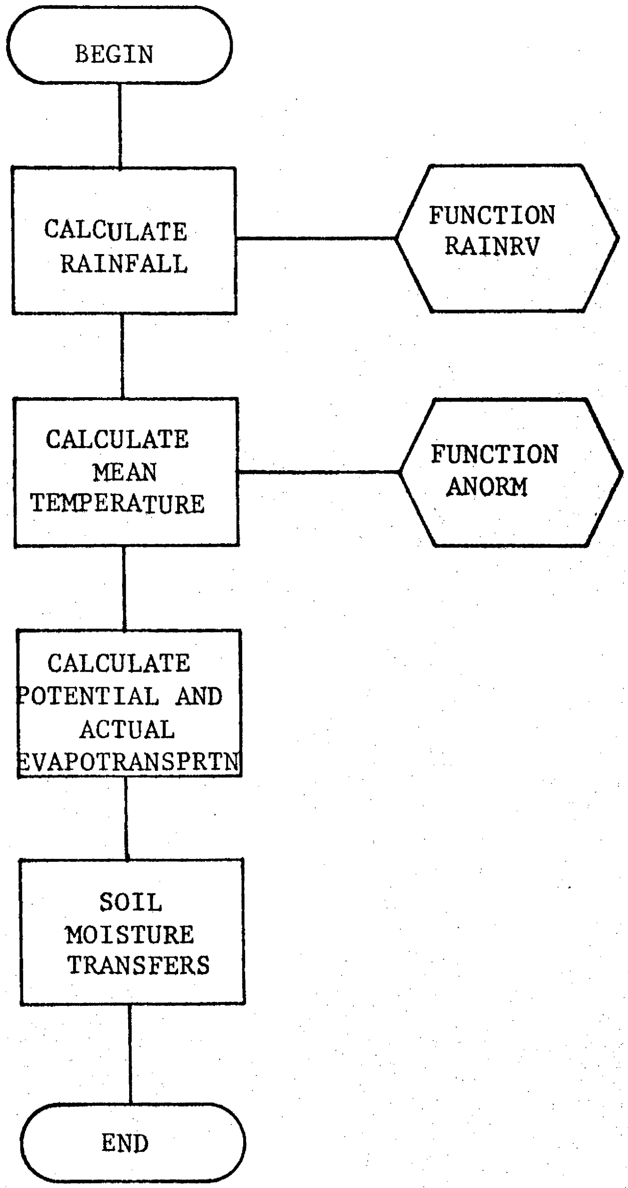

Figure 2.1 - Flow-chart of the climate generator

Phillips (1971) discussed several methods of sampling that produce realistic results. These methods included recursive regression and conditional probability models. Alternatively, if large enough sampling periods (n days) are selected, independence of successive sampling periods can be assumed. Hence, the total rainfall for each n-day period can be obtained by random sampling. Sampling within each n-day period can be based on an analysis of historical data to define the conditional probabilities of m wet days given the rainfall for an n-day period. Phillips considered that for a sample of data he dealt with, successive seven day totals of rainfall could be considered as independent.

A further approach has been used by F.H.W. Morley (pers. comm.). Whether rain fell or not is first determined and if it did, then the amount that fell is calculated. This is thus a two-stage approach as opposed to the more direct methods discussed by Phillips. The method used in CLISIM is a two-stage approach; the probability of rain depends on whether or not rain occurred on the previous day.

Twenty-five years' daily rainfall data were obtained from the Agricultural Research Station Wollongbar, NSW. The data were divided into monthly groupings and analyses performed on data for each month. The procedure followed was outlined by Gabriel and Neumann (1962) and involved determining the probabilities of rain conditional on whether rain fell or did not fall on the previous day, i.e.

$$p_0 = \Pr(\text{wet day} \mid \text{previous wet day})$$

$$p_1 = \Pr(\text{wet day} \mid \text{previous dry day})$$

The twelve monthly values of p_0 and p_1 were now fitted by the least squares method to provide the following equations;

$$p_0 = .570 + .096*\mathrm{SIN}(Z-.133) + .019*\mathrm{SIN}(2*Z-1.135)$$
$$(R^2 = .927)$$

$$p_1 = .216 + .068*\mathrm{SIN}(Z+.923) + .009*\mathrm{SIN}(2*Z-.495)$$
$$(R^2 = .971)$$

where $Z = 2\pi/365*\mathrm{LDAY}$

LDAY takes the value 1 on Jan 1, 2 on Jan 2 .... 365 on Dec 31.

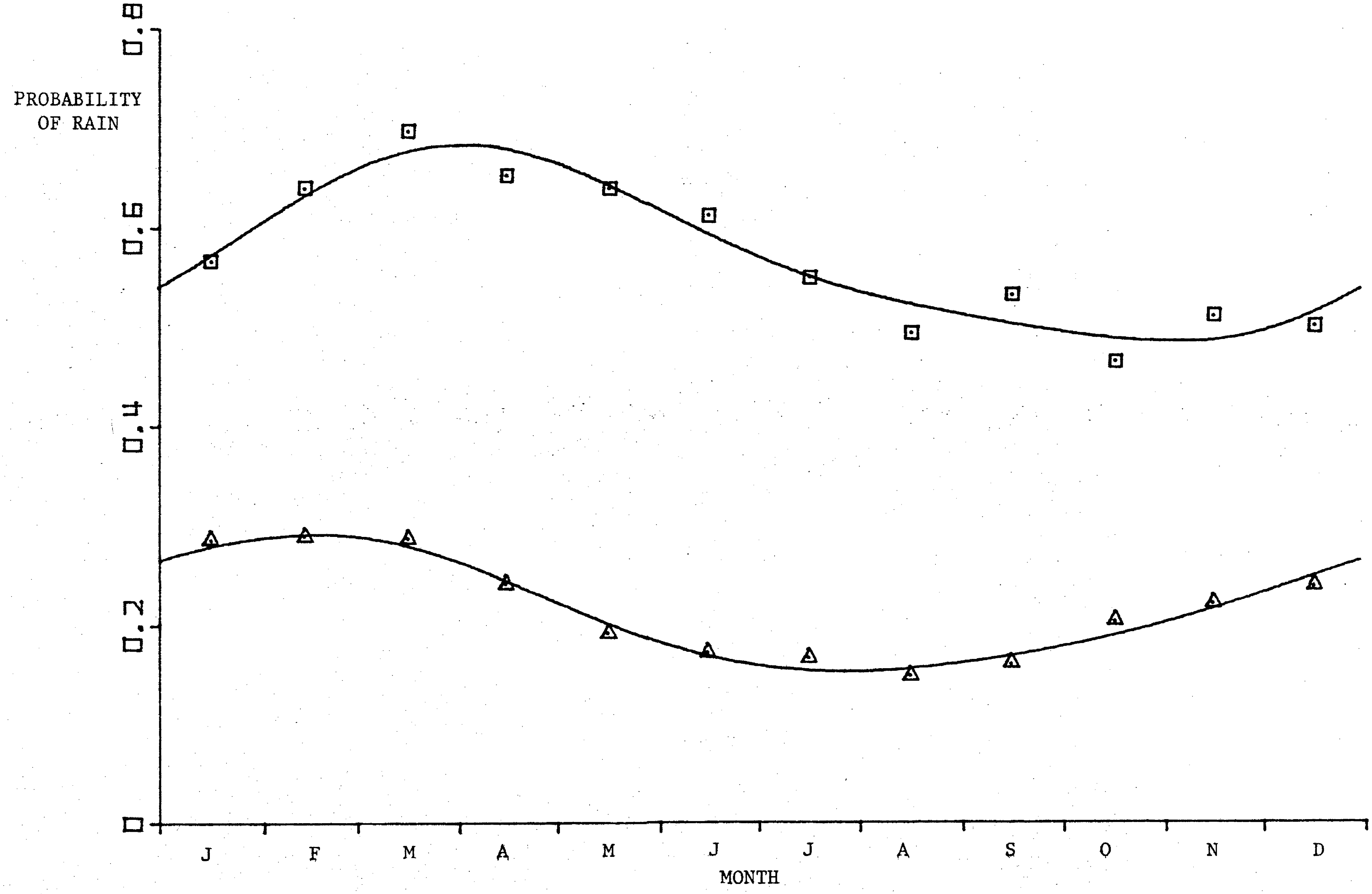

Figure 2.2 - Probability of rain on a day given that it did (upper curve) and did not (lower curve) rain on the previous day

These functions are presented in Figure 2.2. Using these equations and the random number generator, sequences of wet and dry days can be calculated. If it is determined that rain fell on a particular day, the next step is to estimate how much fell. This requires knowledge of the rainfall probability distribution.

The probability distribution of rainfall has a positive skew and consequently a number of asymmetric distributions have been used to describe it. F.H.W. Morley (pers. comm.), Walker and Rijks (1967) and the Bureau of Meteorology have used the log-normal distribution although Das (1956) demonstrated that his (Das 1955) use of a truncated Pearsonian type III distribution was more appropriate for the rainfall data of Sydney. Phillips (1971) advocated several other Pearsonian distributions (Types I, IV and VI).

An examination of the distribution of the daily rainfall recorded in each of the twelve months was obtained. These data were plotted as histograms using class intervals of 2.5mm. All plots had a similar distribution in which the ratio of the standard deviation to the mean averaged 1.6 and showed no evidence of seasonal variation. The histogram of the January distribution is shown in Figure 2.3. There was a seasonal variation in the mean rainfall recorded on rainy days. This seasonal variation is described by the variable EXRAIN (Figure 2.4) :

$$\text{EXRAIN} = 12.02 + 2.5*\text{SIN}(Z-.02) - 0.98*\text{SIN}(2*Z-1.24)$$

$$(R^2 = .818)$$

where $Z = 2\pi/365*\text{LDAY}$

The plotted distributions had an appearance very similar to that of a chi-squared distribution with one degree of freedom. The chi-squared distribution would have an expected ratio of standard deviation to mean of $\sqrt{2} = 1.41$ (Larson 1969). A chi-squared distribution with one degree of freedom is the same distribution as that formed by squaring a standard normal variable and thus, raising the absolute value of a standard normal variable to some power greater than two seemed likely to provide a distribution with the requisite

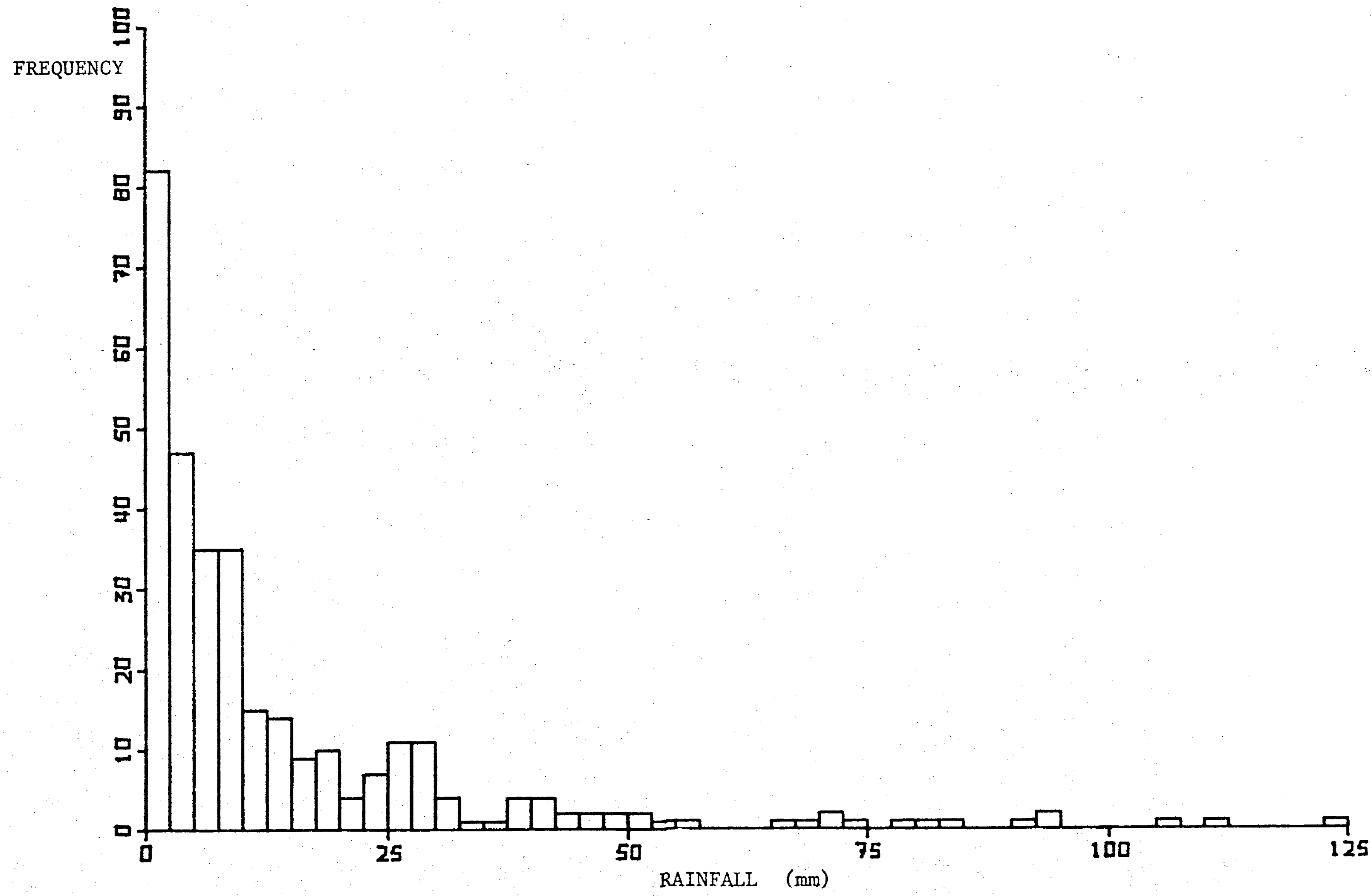

Figure 2.3 - Histogram of the frequency with which daily falls of rain were recorded in January. Data from 25 years has been plotted, except that one recording of 250mm was omitted

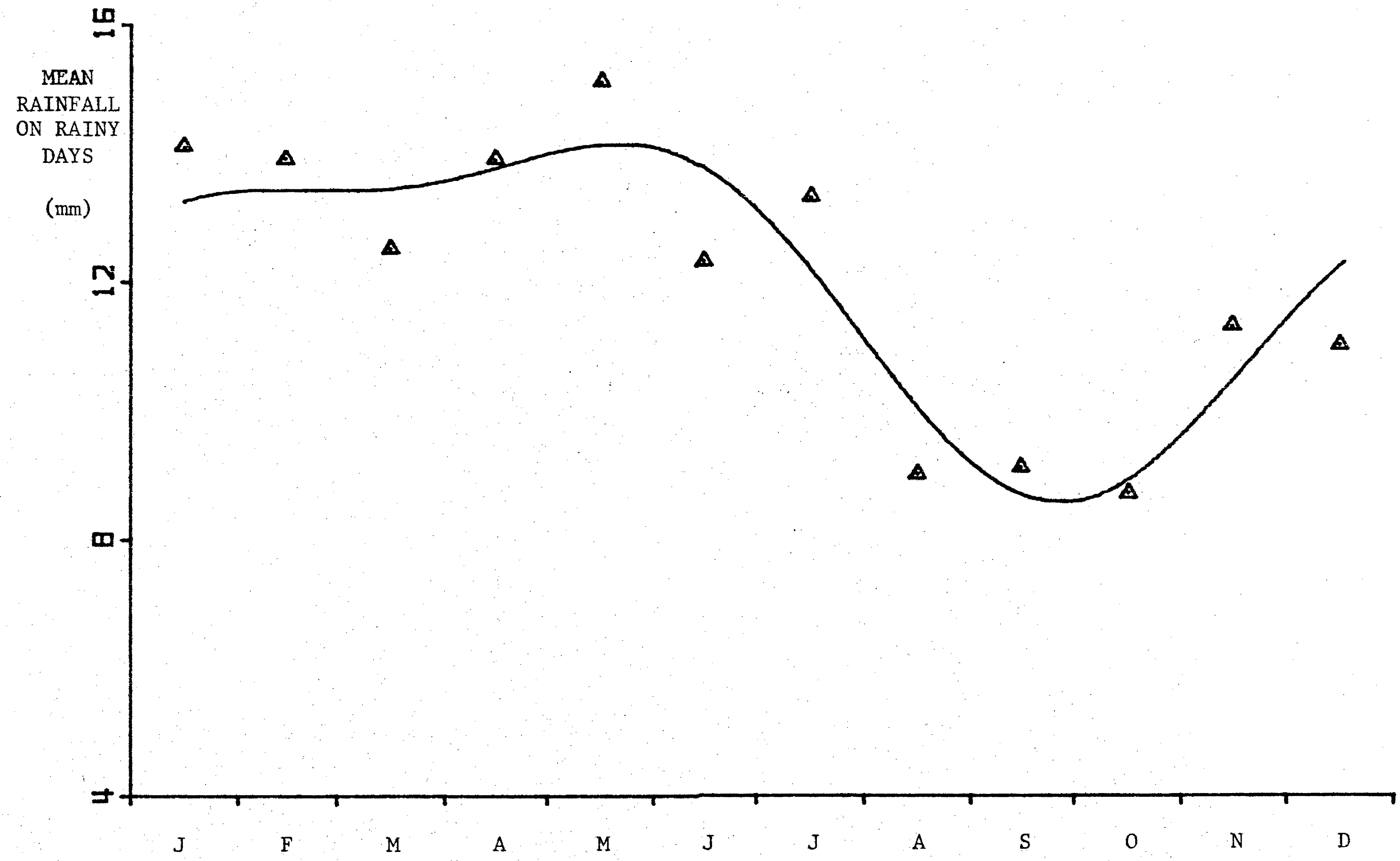

Figure 2.4 - Mean rainfall on days when rain was recorded (25 yr average)

form and ratio of standard deviation to mean. A number of trial values were evaluated and 2.3 was found to be a suitable power. The random variable generated this way had an expected value of about 1.12. Hence, rainfall is calculated by raising the absolute value of a standard normal variable to the power of 2.3, dividing by 1.12 and multiplying by EXRAIN. This random variable is generated in the function sub-program RAINRV.

A comparison of the mean monthly rainfall records generated by this method over a period of 200 years showed no significant departure from the twenty-five years' data on which it was based. The distribution of monthly and yearly totals also appeared realistic. Thus, this method of rain generation was employed in the model. The method of generation is not completely realistic when heavy falls of rain occur. When the region is influenced by a cyclonic depression the chance of heavy falls on successive days is high but this tendency for successive days of high rainfall has not been incorporated into the rainfall generator. This failure to faithfully reproduce rainfall patterns will probably not be important because whether one, or a series of days of heavy rainfall occurs, the soil will reach field capacity. Little reliance can be laid on the fact that the generated data were not significantly different from the observed; the between year variation is such that the 25 years' data from 1911-1935 was found by the X^2 test to come from a different population than the 1936-1960 sequence with a probability of greater than 95%.

Temperature

Between-year variation in mean temperature is relatively smaller than the between-year variation in rainfall. The probability distribution of daily temperature is also more convenient. Thus, generation of realistic seasonal patterns is much simpler for mean daily temperature than for rainfall.

The mean daily temperature for rainy and for dry days in each month was calculated. Negligible differences were found between these means within a month. The maximum difference occurred in mid-summer and mid-winter and was about 1 deg. Because differences of this order were not considered likely to have a great affect on the model's behaviour, the assumption was made that no differences existed between the expected temperature on wet and dry days.

The expected temperature (EXTEMP) for any day is predicted from the following periodic equation

$$\text{EXTEMP} = 18.72 + 4.61*\text{SIN}(Z+1.287) + 0.59*\text{SIN}(2*Z-1.512)$$
$$(R^2 = .998)$$

whilst the standard deviation of the temperature (SDTEMP) was given by the following equation (Figure 2.5)

$$\text{SDTEMP} = 5.32 - 0.629*\text{SIN}(Z-.927) + 0.747*\text{SIN}(2*Z-1.396) + 0.496*\text{SIN}(3*Z-.380)$$
$$(R^2 = .693)$$

where $Z = 2\pi/365*\text{LDAY}$

The results of Thom (1973) and the plot of the daily temperature data for each of the twelve months, suggested that the temperatures were normally distributed. In the model, the actual deviation from the expected value is calculated by sampling from a normal distribution with standard deviation defined by the above equation. In order to produce a correlation with the previous days' temperature this value is added to the previous days' temperature and the average taken. This procedure lowers the variance of the estimated temperature; however, it was found by simulating this process that multiplying the predicted standard deviation by 1.732 produced data of the correct variability.

Evapotranspiration

One of the more difficult problems that confront applied plant physiologists is the estimation of evapotranspiration from a field crop (de Wit 1958). Because of this difficulty and because of the relative ease with which free water (pan) evaporation can be measured, this latter measurement is often employed to predict potential evapotranspiration. Actual evapotranspiration is then calculated as a fraction of potential (Flinn 1971).

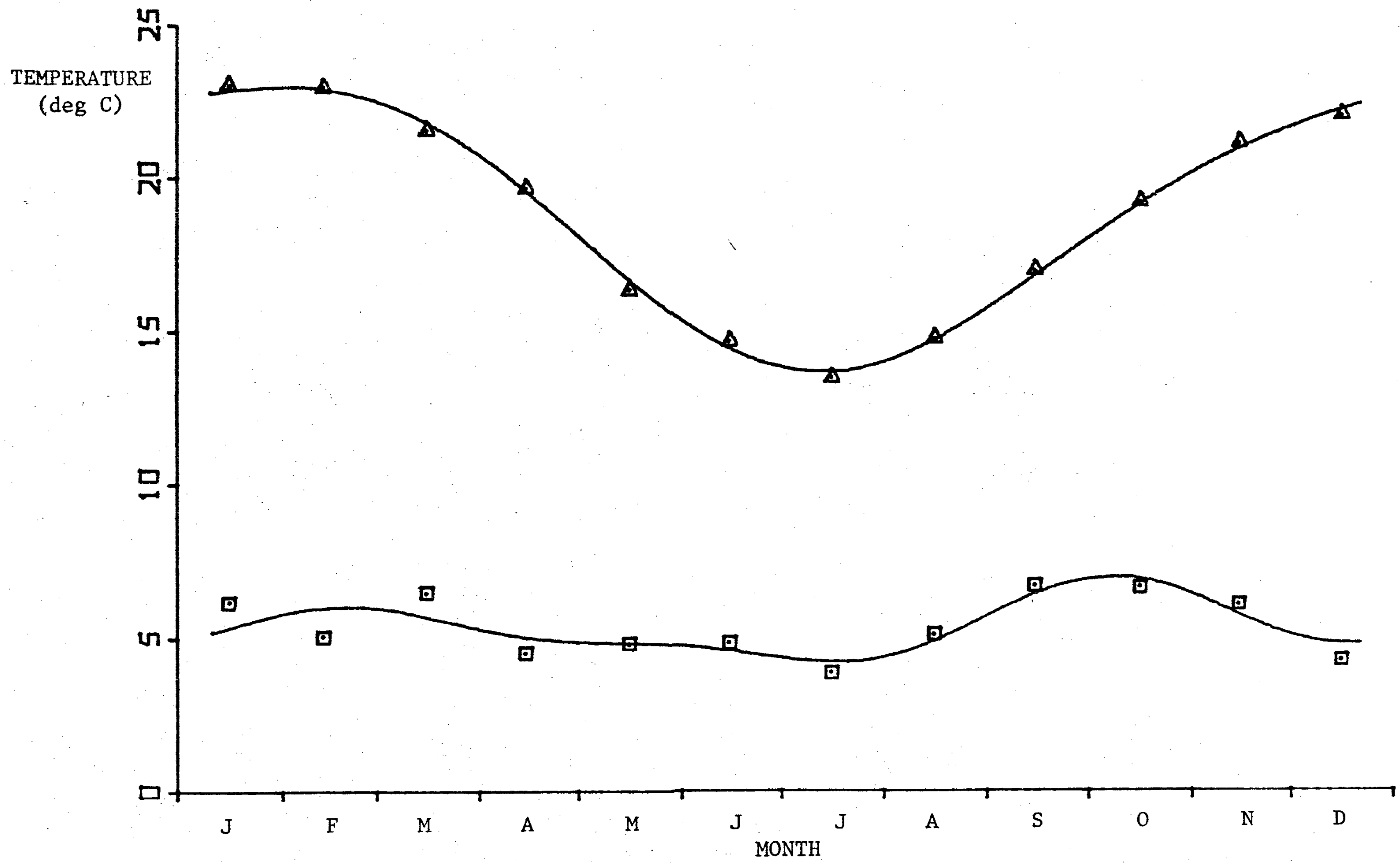

Figure 2.5 - Mean daily temperature (upper curve) and standard deviation of mean daily temperature (lower curve)

The first step in such an approach is to predict daily potential evapotranspiration (E_t) from daily pan evaporation (E_0). The relationship between pan evaporation and potential evapotranspiration is generally assumed to be linear (Slatyer 1967):

$$E_t = k_1 k_2 E_0$$

where k_1 is the "pan factor" and k_2 the "crop factor". The pan factor is associated with different evaporation pans and depends on the type of pan and its placement (above, at or below the ground surface). The crop factor depends on the plants or sward being considered and their coverage of the ground. Generally, no attempt is made to separate the values of k_1 or k_2 for simulation studies, as it is their product which is required. Estimates of this product for a sward have varied, with the majority being in the interval (.6,.9). Penman (1948) noted that the coefficient was lower in winter than summer. His results were variable but a difference of about .2 appeared to exist between the seasons. Consequently, the following function is used to define the parameter PENMAN, which is the product of k_1 and k_2

PENMAN = 0.6 + 0.1*SIN(Z+1.5708)

where Z is as defined above. Hence the summer value for PENMAN is .7; the derivation of this value is described in Chapter 5.

It is worthwhile noting that had a larger value of PENMAN been chosen it could be made to have no effect on the model merely by increasing the size of the soil moisture pool. This is an example, not rare in simulation modelling, where no real gain is obtained from an accurate determination of a single parameter. In this case, if extra accuracy is to be of benefit it must be achieved concurrently in a set of paramters.

The prediction of evaporation from a US Class A pan is based on an analysis of three years data obtained from the Alstonville Tropical Fruit Research Station. A regression was calculated to estimate pan evaporation (POTEVP) taking into account the mean daily temperature (TEMP), whether it rained (KPREV=1) or not (KPREV=0), and time of the year

$$\begin{aligned}\text{POTEVP} = 3.28 + 0.111{*}\text{TEMP} + 0.00101{*}\text{TEMP}{**}2 \\ - 1.12{*}\text{KPREV} - 1.13{*}\text{SIN}(\text{Z}-1.29) \\ (R^2 = .283)\end{aligned}$$

where $Z = 2\pi/365{*}\text{LDAY}$

The coefficient of determination of this regression was not substantially improved by either the inclusion of TEMP^3 as a variable or estimation of the second harmonic. Although the coefficient of determination was low, it was not as low as some of the values reported by Fitzpatrick (1963) in which temperature was the only independent variable. The lower values reported by Fitzpatrick also came from a coastal environment whereas inland values were uniformly high ($r > .9$).

Actual daily evapotranspiration (E_a) is calculated from a consideration of the evaporative demand of the environment and the estimated ability of the plant to meet that demand. Details of the method are outlined in Appendix A and only a summary follows.

If the potential evapotranspiration, daylength and pattern of evaporative demand within a day are known, it is a straightforward matter to calculate the instantaneous rate at which water must be supplied to meet that demand. In particular, if the maximum rate at which a plant can transpire (dE_m/dt) exceeds the rate at which the environment can extract moisture (dE_t/dt), then the plant's actual rate of transpiration (dE_a/dt) is assumed to be equal to the environmental demand rate. On the other hand, if dE_t/dt exceeds dE_m/dt, then the actual rate of moisture loss is assumed to be equal to the maximum rate the plant can sustain (dE_m/dt). This model of transpiration was proposed by Fleming (1964) and can be summarised as,

$$dE_a/dt = dE_t/dt \quad \text{if} \quad dE_m/dt \geq dE_t/dt$$
$$dE_a/dt = dE_m/dt \quad \text{if} \quad dE_m/dt < dE_t/dt$$

Two day-time patterns of evaporative demand were investigated (Appendix A), one in which demand was typical of a cloudless day and followed a sine curve, and the other in which the demand was typical of a cloudy day and followed the curve described by Fleming (1970). The different patterns of demand made virtually no difference to the estimates of E_a, so the computationally simpler method (assuming a cloudy day) has been used in the model. This function is presented in Figures 2.6 and 2.7.

Soil moisture is considered to be held in two layers. Because the density of plant roots is greatest in the top layer, it can provide moisture at the greater rate. The ability to supply moisture declines linearly as soil moisture declines from field capacity to wilting point, as has been proposed by Fleming (1964) and Baier and Robertson (1966). The rates of evapotranspiration at field capacity for the two layers are 1.5 and 0.6 mm hr^{-1}. The ratio between these two values (2.5) is similar to that which gave the best fit to the data of Baier and Robertson (1966) for soil profiles of similar depths. The esimate of 1.5 mm hr^{-1} as the maximum rate of evapotranspiration is based on rates of this order estimated by van Bavel (1966) using alfalfa. The species and the environment were different from those being considered in the model, nonetheless the estimates of van Bavel provide an indication of the sort of evapotranspiration rates that plants in the field can maintain.

This approach is quite different in priciple to that in which the value of E_a is calculated from an estimate of E_a/E_t; most models calculate the ratio then derive E_a. Vickery and Hedges (1972) and Smith and Williams (1973) describe this ratio as a function of soil moisture, whereas G.T. McKinney (pers. comm.) has developed an equation which uses both soil moisture and E_t to define the E_a/E_t ratio - an approach recommended by Flinn (1971). A major difference between the approach used in the model and that of the above models is that in this model if E_t is very high then, even at field capacity, the E_a/E_t ratio may not be unity (Figure 2.7). Conversely, at low soil moisture the ratio may equal 1 if E_t is sufficiently low. Thus, in one sense, the present approach results in a more sensitive tracking of the environment. Whether it is closer to the true response is another question, however, the curves presented in Figures 2.6 and 2.7 bear a close relationship to those found experimentally by Denmead and Shaw (1962).

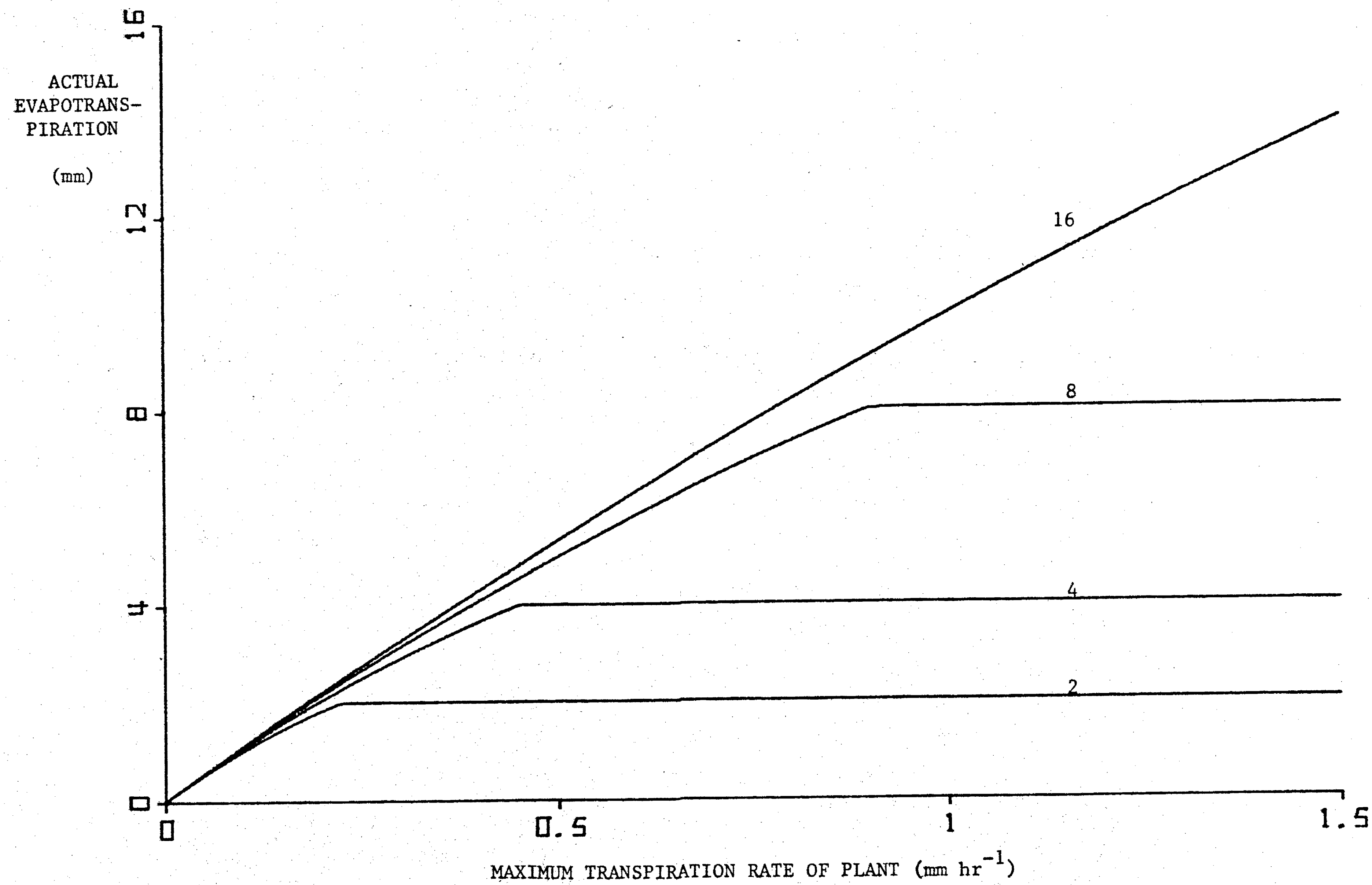

Figure 2.6 - The relationship between actual evapotranspiration on a 12hr-daylength day and maximum transpiration rate. Numbers on curves indicate the potential evapotranspiration (mm)

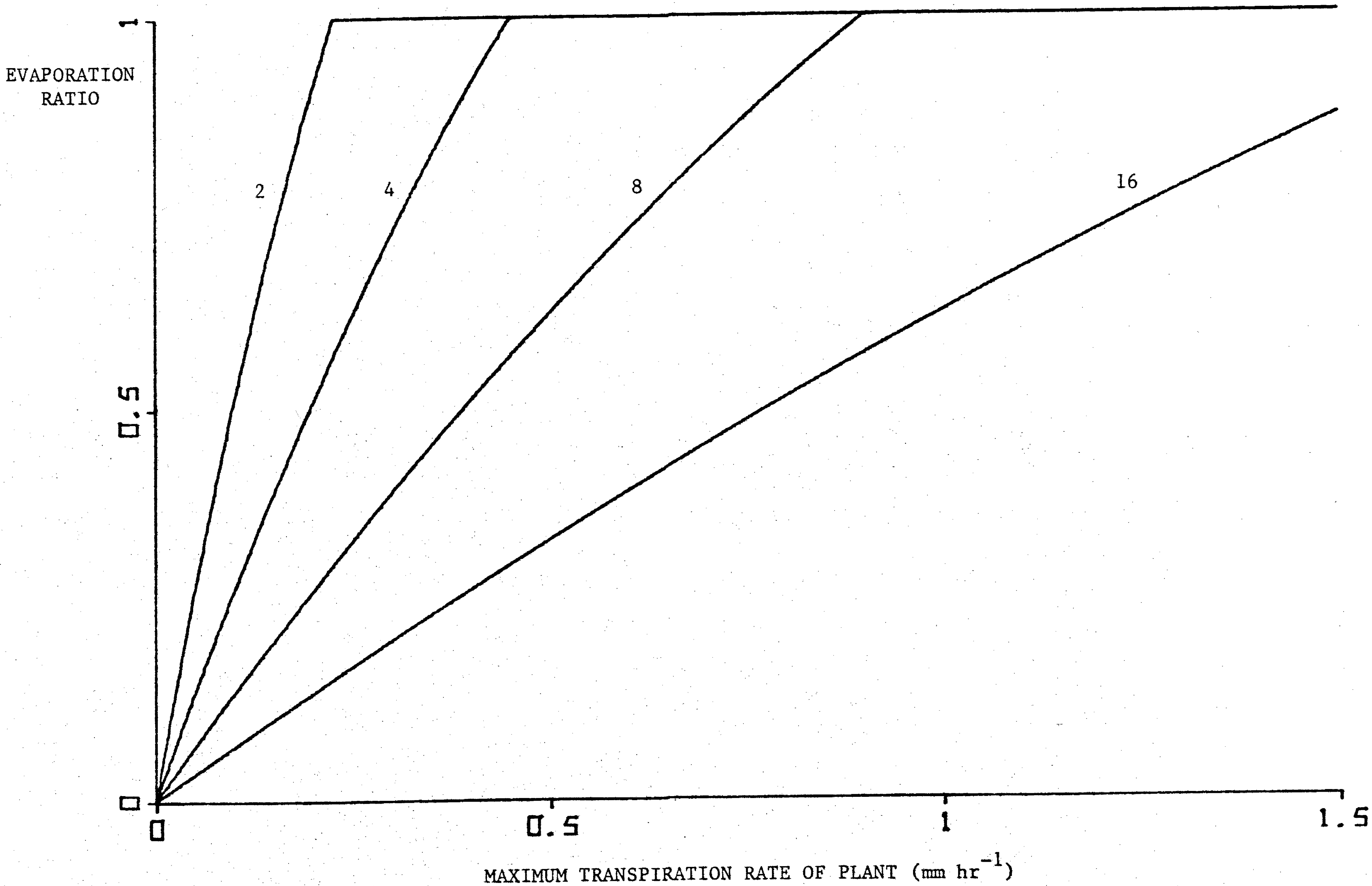

Figure 2.7 - The relationship between evaporation ratio on a 12hr-daylength day and maximum ... Numbers on curves indicate the potential evapotranspiration (mm)

Soil Moisture Budget

After rainfall, actual evapotranspiration and rainfall run-off have been determined, the estimation of the amount of moisture in the soil becomes a straightforward budgetary exercise (Flinn 1971). The rules for the budget vary between models depending largely on the number of soil compartments considered and the transfers between the compartments.

In the present model the soil is considered as being composed of two layers. The depth of each layer is read into the model with its wilting point, field capacity and field saturation. Saturation occurs only after both layers have reached field capacity; it is a short-lived phenomenon with a three day duration (T. Talsma pers. comm.). A soil which has a moisture content greater than field capacity quickly declines towards field capacity with 0.7 of the excess being removed each day. Any excess removed from the top layer percolates into the lower one.

The values of wilting point, field capacity and field saturation used in the model are presented in Table 2.1; they were obtained from measurements made on krasnozem soils on the Atherton Tableland (D.A. Gilmour, unpub. data). The site at which the measurements were made was an improved dairy pasture; wilting point and field capcity were defined to be 15 and 1/3 bar respectively.

Table 2.1 - Constants used to define the moisture characteristics of the soil

Attribute	Upper Layer	Lower Layer
Depth(mm)	0-250	250-750
Wilting point*	.15	.20
Field capacity	.35	.30
Field saturation	.40	.35
Storage at field capacity(mm)	50	50
Transpiration rate at field capacity(mm hr^{-1})	1.5	.6

* wilting point, field capacity and field saturation are expressed as the ratio of the volume of moisture in the soil to total soil volume. Thus the wilting point estimate for the upper layer being .15 implies that .15x250 = 37.5mm of moisture is present in the upper layer at wilting point.

Run-off is ignored in this model, partially because the soils are very porous at moisture contents up to field saturation and partially because no reliable estimates of run-off exist. In advocating such an approach, F.X. Dunin (pers. comm.) reasoned that when run-off is likely to be large the soil will almost certainly be at field capacity. On the north coast this is mainly likely to occur in summer.

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Chapter 3

THE PASTURE SUB-MODEL

The pasture sub-model calculates the increment in above-ground plant growth that occurs each day, distributes this increment depending on the reproductive status of the plant and determines the senescence and decay rates. Four pasture species are considered : carpet grass (*Axonopus affinis* Chase), paspalum (*Paspalum dilatatum* Poir.), kikuyu (*Pennisetum clandestinum* Hochst.) and naturalized white clover (*Trifolium repens* L.). The shoot dry-matter of each of these species is composed of six pools :

Pool Number	Material in Pool
1,2,3,4	Green leaf, sheath and stem
5	Dead tissue
6	Inflorescences and stems.

As material in pool 1 ages it passes into pool 2; ageing material in pool 2 passes into pool 3 and so on until the live tissue has died and entered pool 5. Dying inflorescences and their associated stems pass from pool 6 to pool 5.

Reproduction is only considered in carpet grass and paspalum. The reproductive phase in kikuyu has not been included as it does not appear to have any significant effect on the vegetative tissue and is, in general, inconspicuous (Carr and Ng 1956 ; Younger 1961). White clover reproduction was not considered as it makes no obvious difference to the growth characteristics of a sward and it is doubtful whether cattle could select either for or against clover flowers.

A flow chart of the pasture submodel is shown in Figure 3.1. Growth of each species is considered to be a function of the amount of photosynthetically active tissue, environmental variables and soil fertility. The model has not attempted to consider the separate effects of photosynthesis and respiration, nor has the transfer of

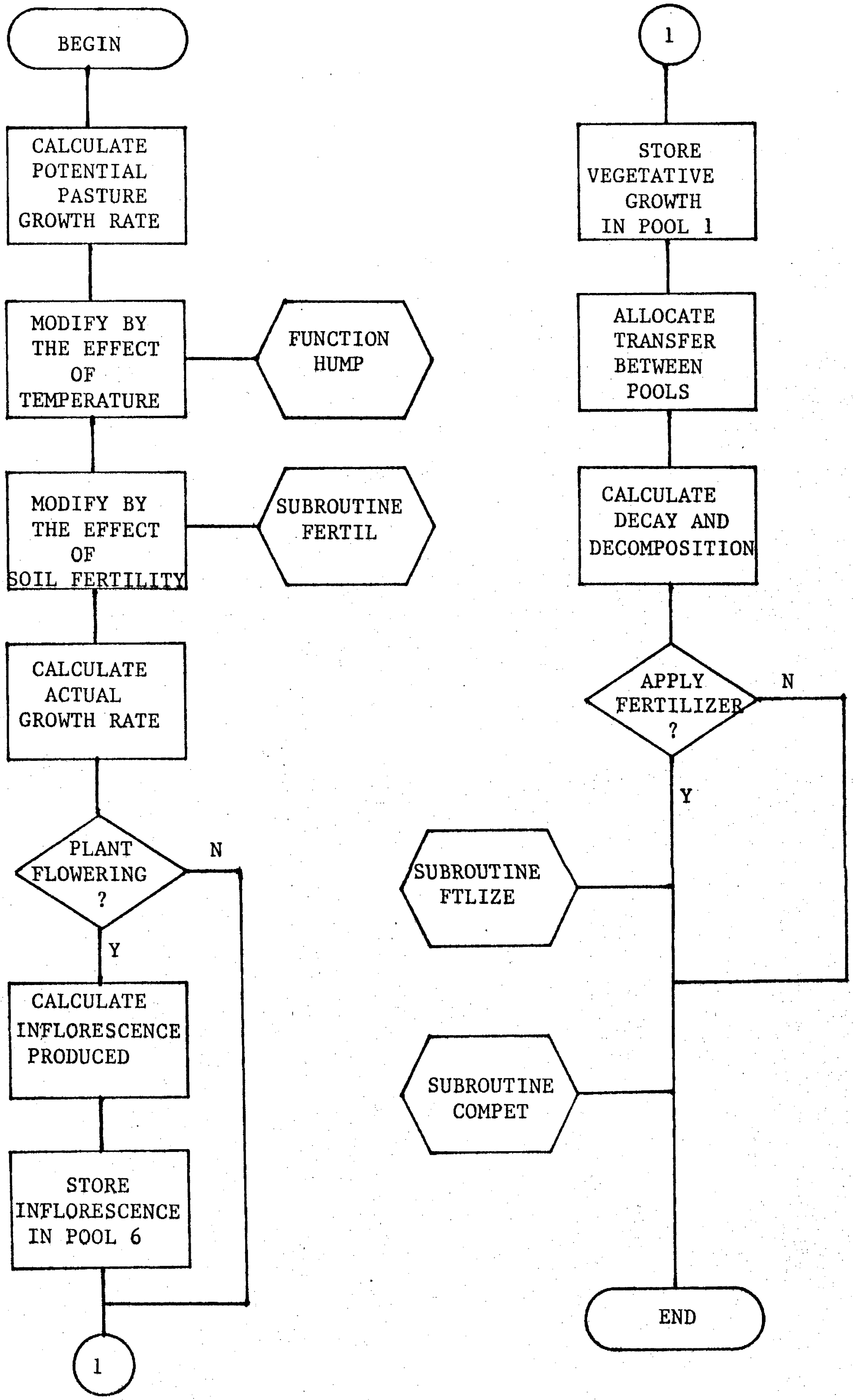

Figure 3.1 - Flow-chart of the pasture sub-model

nutrients within the plant been incorporated in the model. The four green leaf, sheath and stem pools have been included to allow a representation of ageing within a pasture sward - the pools have no physical counterparts.

It is assumed that elements other than phosphorus (P) and nitrogen (N) are not limiting pasture production although the results of Anderson and Arnot (1953) indicate that this is almost certainly incorrect. Only P and N are considered in the model as the economic and energetic cost of maintaining adequate amounts of most other elements is relatively small. Thus, even if deficiencies of elements other than P and N are widespread, the costs of correcting these deficiencies will probably be low enough to allow the major conclusions of experiments with the model to still apply.

Environmental Effects

Two environmental variables are considered to directly affect plant growth in the model. They are temperature and the ratio of actual to potential evapotranspiration (evaporation ratio). Light can have an effect on plant growth either by virtue of its intensity or its duration (photoperiod). The effect of varying intensities of radiation on plant growth has not been considered in the model because radiation was considered not likely to limit production in the environment under study (Colman 1971). The results of Knight (1955) with paspalum suggest that photoperiod changes can influence growth directly and, also, indirectly by the induction of flowering. No direct effect is considered in the model because the unconfounded extraction of such an effect from Knight's data was not possible; however, flower induction has been included.

Effect of temperature

The shape of the function relating growth to temperature is shown in Figure 3.2. This general shape is characteristic of the response of "activity" of biological organisms to temperature changes (Wigglesworth 1950; Went 1957). An almost identically shaped curve was used by Vickery and Hedges (1972). The response is the expression of the equilibrium

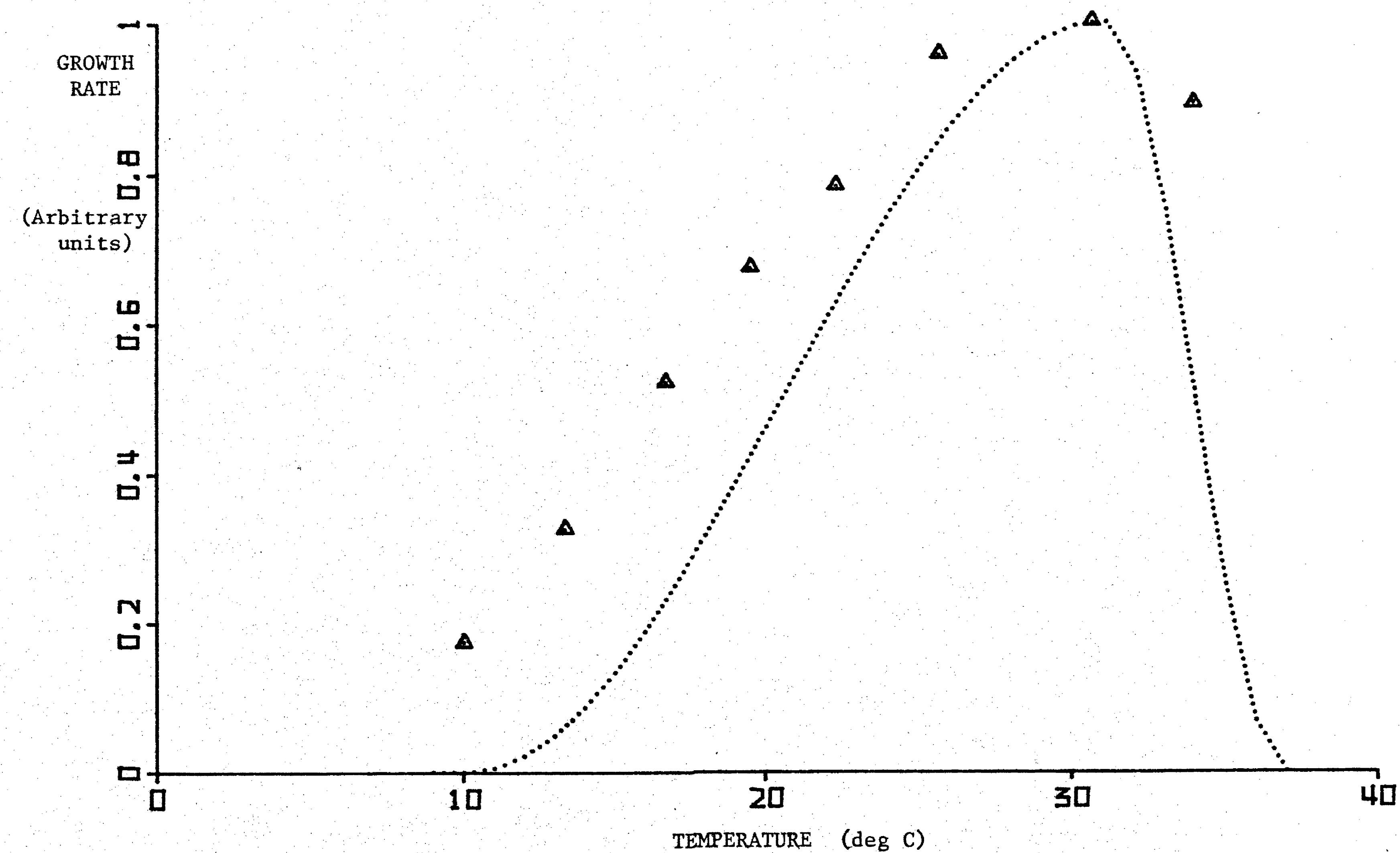

Figure 3.2 - Temperature/growth rate relationship used in the model for Paspalum. Data plotted were estimates obtained from Mitchell (1956)

reached as temperature increases thereby increasing reaction and diffusion rates till finally a critical temperature is reached beyond which the negative effects of an increased rate of enzyme denaturation exceed any increase due to increased reaction and diffusion rates.

It will be noted that the temperature/growth rate response curve used in the model is "to the right" of Mitchell's (1956) observations (Figure 3.2). This displacement was made because the paspalum on the NSW north coast is almost certainly a different and less cold tolerant ecotype than the New Zealand ecotype used in Mitchell's studies. The effects of acclimatization on the development of many species of plants has been recognised for at least a century (Schimper 1903). The derivation of the functions used to define the curve in Figure 3.2 is presented in Appendix B. The curve is defined by three parameters : the temperature below which no growth occurs, the temperature of maximum growth and the temperature above which no growth occurs.

Although the temperature at which maximum growth occurs can be defined in growth cabinet studies, the determination of the mean daily temperature at which maximum growth occurs is not as straightforward. One reason is that non-linearities in the temperature/growth response curves (Figure 3.2) prevent the direct comparison of the temperatures recorded by Mitchell with mean daily temperatures (Williams 1969). Diurnal temperature changes alone can cause apparent inconsistencies, e.g. consider two days with mean temperatures of 20 deg, one in which the temperature ranged from 15-25 deg, whereas in the other the range was 10-30 deg. If no growth occurs below 25 deg, then clearly although the mean temperatures are identical, growth will occur only on the second day. For this reason the relationship between growth and a simple measure of daily temperature can only be approximate. Also, Evans (1963) has pointed out that plants of some species grown in an environment in which temperature remains constant will develop abnormally.

The parameters used to define the temperature/growth response curves were based on the work of Mitchell (1956) with less emphasis being placed on the less definitive publications of Knight and Bennett (1953), Knight (1955), and Evans, Wardlaw and Williams (1964). The views of research workers familiar with the responses of the species being studied to the north coast environment also influenced the finally selected values.

Table 3.1 - Temperatures used to define temperature/growth rate relationships.

Species	Temperature below which no growth occurs	Temperature of maximum growth	Temperature above which no growth occurs
Carpet grass	12	31	37
Paspalum	10	31	37
Kikuyu	8	28	34
White clover	0	25	29

Estimated leaf temperature, rather than mean daily temperature, is used in the model to asses the effect of temperature on plant growth rate. Linacre (1964) reviewed the relationship between leaf and air temperatures. Up to about 35 deg, the leaf temperature exceeded the ambient temperature; the relationship between leaf temperature (TEMPLF) and ambient temperature (TEMP) for well watered plants was approximated by

TEMPLF = 9.0 + .74*TEMP

From the theoretical considerations of Linacre (1964, 1971) and the review of Evans (1963) it is clear that if plant transpiration is reduced, e.g. by low soil moisture, then the leaf temperature will increase. Hence, in the model, for every millimetre difference between potential and actual transpiration the leaf temperature is taken to rise by 1 deg.

Effect of Transpiration

The method of estimating potential (EVPOT) and actual (EVACT) evapotranspiration has been outlined in the description of the climate generator. From these two variables the evaporation ratio (RATIO) is calculated

RATIO = EVACT/EVPOT

Hence, the evaporation ratio lies in the interval (0,1). Potential plant growth is multiplied by the value of RATIO to define the effect of evaporative demand and soil moisture on plant growth.

De Wit (1958) suggested that plant growth rate was proportional to evaporation ratio. His analysis of data existing at that time from "climates with a large percentage of bright sunshine" supported such an hypothesis; however, data from the Netherlands did not. Although de Wit argued that light intensity had an important influence on the relationship between dry matter production, transpiration and free water evaporation he did not include it in the equation relating these variables. Consequently, the relationships he suggested can in no sense be universal. Despite this, a proportional relationship between growth and evaporation ratio has been assumed in the model. The models of Freer et al. (1970) and Wright (1970) made the same assumption. Vickery and Hedges (1972) defined plant relative growth rate as a function of soil moisture. This function was almost identical to the function relating soil moisture to evaporation ratio, hence Vickery and Hedges virtually assumed that direct proportionality existed between growth rate and evaporation ratio.

Before the dynamics of a growing pasture can be fully understood the quantitative effects of moisture stress on the growth rate of a pasture sward need to be defined. De Wit's analysis implicates actual evapotranspiration, free water evaporation and light intensity. The effect of the controlled variation of these three variables on the growth rate of a sward, in say, a 3^3 factorial arrangement of treatments, would be a useful starting point.

Effect of Amount of Tissue

Medawar (1941) defined the second "law" of biological growth to be "what results from biological growth is itself, typically, capable of growing". This thought is implicit in all the "growth equations" which have been developed, i.e. they can all be expressed in the form

$$dW/dt = f(W)$$

where dW/dt is the instantaneous rate of change of tissue weight (growth rate), and W represents the amount of tissue at any one time and f(W) is a function. The best known growth functions are the monomolecular, autocatalytic (logistic) and Gompertz curves.

Published work describing either the use or development of growth functions generally falls into one of two classes. There are authors who speak of "laws" of allometry and growth (Bertalanffy 1957), whilst others are more pragmatic and speak of empirical curves (Richards 1959, 1969 ; Gould 1966; Pienaar and Turnbull 1973). The interpretation of Williams (1964) is neither in one class nor the other. Williams compared the results of fitting a logistic and a cubic polynomial to some wheat growth data. He described the cubic as "being less exacting in the assumptions it makes". The fact that Williams saw the logistic imposing assumptions implies he was using it in the Bertalanffy sense as a curve which defined a "law of growth". On the other hand, the second curve Williams fitted was a cubic polynomial which was chosen as it is a useful empirical curve likely to give a good description of the data points. Thus, the philosophy implicit in Williams' fitting of the logistic curve was diametrically opposed to that used when fitting the cubic polynomial. Consequently, the logistic was rejected on an invalid basis. If a logistic and a cubic polynomial are, in some sense, to be compared, then the comparison is only valid if both are regarded as empirical.

Richards (1959, 1969) discussed, in some detail, the fitting of growth curves. He pointed out that the curves can only reasonably be regarded as being empirical, but that these curves are more useful if "the constants yield information of direct biological interest". For this reason Richards' (1959) growth curve was used in the model to describe the relationship between the amount of photosynthetically active tissue and growth rate, rather than using a polynomial (Wright 1970) or some other function (Freer et al. 1970; McKinney 1972 ; Smith and Williams 1973).

Richards growth curve is expressed by the differential equation

$$dW/dt = kW((A/W)^{1-m}-1)/(1-m) \qquad (1)$$

where k is a rate constant, A defines the maximum value W can attain and m is a positive constant, not equal to unity. Changes in the value of the constant m change the shape of the curve, for example m = 2 results in (1) being equivalent to the logistic and as m approaches 1 the curve approaches the shape of the Gompertz curve. The above-ground growth of an annual species, growing from seed will follow a different curve from a perennial species in which a well developed root system is present at the start of the season. Plants growing from seed tend to follow a curve which more closely resembles the logistic (m = 2 with the Richards curve). A perennial with a similar amount of photosynthetically active tissue will follow a curve of the form of (1) where m is less than 2. This implies that maximum growth rate occurs before half the ceiling yield is reached and that within the bounds of experimental error and over the range of agriculturally important yields, growth rate is relatively constant; Brougham (1956), Evans, Wardlaw and Williams (1964) and Mears (1973) amongst others provide evidence that this is the case. The values used in the model for the parameters A, k and m can be found in Appendix D.

In the calculation of photosynthetically active tissue a weighting is put on the estimates from different pools. Since the pools which are regarded as being photosynthetically active (1 to 4) have no physical counterparts this weighting is a purely empirical inclusion. However, it is a concept based on the fact that young leaf tissue has a higher photosynthetic rate than older tissue (Shiroya et al. 1961).

The work of Stern and Donald (1962) demonstrated that high grass yields resulted in a lower light penetration to the subterranean clover canopy and consequently slower growth of the clover. This mechanism also operates with white clover (Mears 1967; Ostrowski 1972). To accommodate this concept in the model, the growth rate of clover is reduced when total availability (PTOTAL) is high. The potential growth rate is multiplied by an amount, F, where

F = 0.25 + 0.75*EXP(-3.0E-8*PTOTAL**2)

Effect of Fertility

The form of the yield response to increasing amounts of a limiting nutrient has been described by a wide range of functions (Tisdale and Nelson 1966; Campbell and Keay 1970). The most frequently used function is the "Mitscherlich curve" which has the algebraic form of

A * (1.0 - EXP(-B*X)) (2)

where B a constant, X the amount of the limiting nutrient and A the yield obtainable at optimum levels of X. Although the Mitscherlich curve is widely used, many examples of a sigmoid response are known (Tisdale and Nelson 1966; Loneragan 1964). If more than one limiting nutrient is supplied, e.g. P and S in superphosphate, then a sigmoid curve may well occur even though the responses to P and S separately follow the Mitscherlich curve. Richards (1969) pointed out that this can merely be a consequence of multiplying together two curves of the form of (2). The three dimensional projections presented by Loneragan (1964) are a good example of how the response to each nutrient separately agrees with the form of the Mitscherlich curve but, if the nutrients are supplied together, the response can become sigmoid. In the model, the response to N and the response to P is assumed to follow sigmoid curves.

Although a number of experiments have been conducted on the north coast in which the response to fertilizer has been measured, their use in modelling is somewhat limited. These experiments provide an estimate of the order of response that can be anticipated but explanations of differential response between sites as "soil fertility differences" are likely to be meaningful, at most, to those familiar with the environment. Even if it had been the intention of the experimenter to provide an analysis of the soil, the results of Simpson (1962) indicate that the measurement of soil nitrogen level could well have been an illusory gain in information.

Because of the dramatic effects that fertilizer can have on botanical composition and consequently potential production (Bryan 1967; Mears 1973), N and P fertility levels were incorporated as variables in the model. However, for the reason outlined in the previous paragraph the actual definition of relative response of the different species to fertility changes is based largely on subjective estimates. The response (FERTF) is determined as the product of two sigmoid curves, the arguments for the curves being the phosphorus and nitrogen contents of the soil. The constants for each curve vary with each species; they can be found in DATA statements at the commencement of subroutine FERTIL in Appendix C. The resultant values of FERTF for a range of soil phosphorus and soil nitrogen levels are shown in Appendix D. Plants respond to increases in available phosphorus (ppm) and nitrogen in the soil. Nitrogen level is defined in arbitrary units which cover the (0,1) interval. Although this is not an entirely satisfactory method of including these variables it was judged to be more realistic than excluding them. The application of superphosphate is taken to increase the available P by .0025 ppm $kg^{-1}ha^{-1}$; 1 kg N ha^{-1} increases the soil nitrogen level by .0016 units. Virtually no information could be obtained on which the values of these two constants could be based. The values chosen appear to give "reasonable" results, though even if the conceptual structure of the model is accepted, the values chosen could be in considerable error. To a large extent any under- or over-estimation of these constants could be compensated for by a choice of smaller or larger values for the constants DKCONN and DKCONP, to be described below.

The basic or native "fertility" of a soil is defined at the beginning of each run in the variables FERTP and FERTN. The actual fertility at any time can be different from the base levels because the growth of clover may have contributed to the soil nitrogen level or because nitrogen or phosphorus fertilizer may have been applied. The actual levels of N and P fertility are stored in variables FERTAN and FERTAP respectively. Following the application of fertilizer, the FERTAN and FERTAP values commence an exponential decline towards FERTP and FERTN levels with decay rates of DKCONP and DKCONN respectively. At the current setting of .0015 and .0060 this means that applied P and N fertilizers have a "half life" of 462 and 115 days respectively. The provision of nitrogen from legume growth is regarded as a continuous process that is directly related to clover growth rate. Every kg ha^{-1} of clover grown increases the nitrogen status by .00005 units.

Actual pasture growth (PGROTH) is then calculated from the potential growth (GROTH) modified by temperature (TEMPF), evaporation ratio (RATIO) and soil fertility effects (FERTF) from the following relation

$$PGROTH=GROTH*TEMPF*RATIO*FERTF$$

Transfer between the Plant Pools

In a simple model of plant growth at least two pools (green and dry) and three rate processes (growth of green, transfer of green to dry (senescence) and transfer out of the dry pool (decay)) are likely to be identified. Further, as has been discussed, feedback will exist between the size of the green pool and the growth rate (Figure 3.3). Also, each of the rate processes will be affected by soil moisture level and, in a non-linear manner, by temperature. Given this complexity in a simple model it is not surprising to find that no unequivocal measurements of the rate processes have been made. Several estimates (Wiegert and Evans 1964; Hunt 1965; Morris 1970) have been made, but they provide an estimate of the order of effect that can be expected rather than a precise estimate of rates.

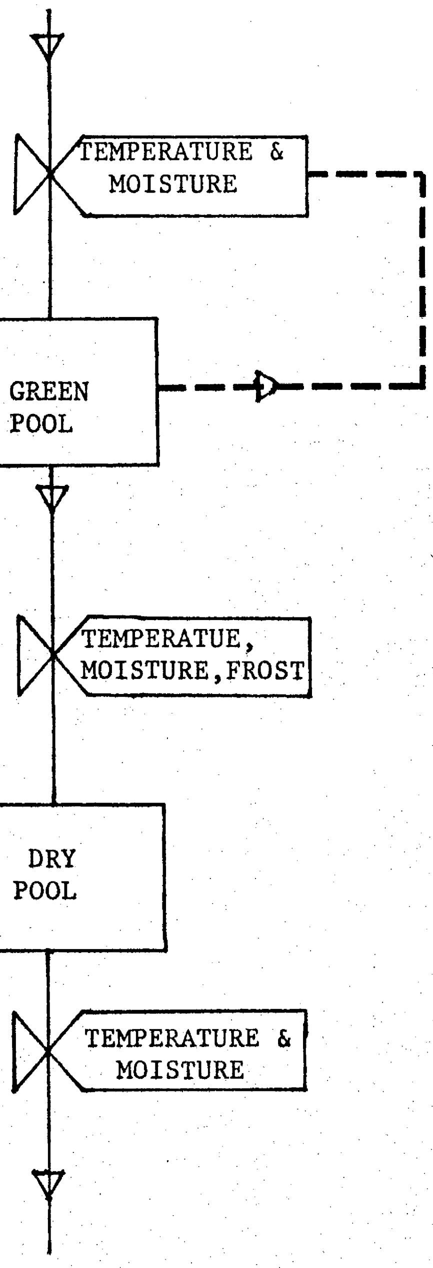

Figure 3.3 - The components of a very simple plant growth model following the symbolism of Forrester (1968). Information flow is shown by the broken line

Senescence

In the following discussion "senescence rate" refers to the rate of transfer between green pools and from green to dry, i.e. from pools 1 to 2, 2 to 3 ...4 to 5 and 6 to 5. Because the non-reproductive green tissue is involved in four transfers before reaching the dry pool, these transfer rates are of the order of four times the size of what is more conventionally termed "senescence".

A plant's response to moisture stress can be to reduce its transpiring surface by the death of some live tissue. However, even in the absence of moisture stress, death of leaves and their replacement occurs. Considering the response of organisms to increased temperature, as already discussed, an increase in senescence rate could be anticipated with increased temperatures. As the temperature increased from low values this would result from increased reaction and diffusion rates; at higher temperatures death would result from protein denaturation and cell death. The increased senescence rate in summer, observed by Wiegert and Evans (1964) in their study of succession on an old field, is consistent with such an hypothesis.

The senescence rate of the green pools is defined as a function of evaporation ratio (RATIO) and mean daily temperature (TEMP). The senescence rate for clover is

```
SENESC = 0.00225*TEMP - 0.030*RATIO
SENESC = AMAX1(SENESC,0.008)
```

where AMAX1 is a Fortran IV function which returns the maximum of a number of arguments.

Dry spells in summer have a greater effect on the senescence of clover than on the grasses (Ostrowski 1972). Thus, the senescence rate of the grasses is less than that of clover and is defined as

```
SENEST = SENESC*0.9
```

The rate of transfer of green to dry can be increased by frosting, especially with the warm climate grasses (Hacker 1974). In the model, "frosting" is defined to occur when the mean temperature drops below 9 degrees. If this occurs, the senescence rate for the grasses is calculated as

SENEST = 0.05 + 0.015*(9 - TEMP)

Decay

Decay and decomposition is largely the result of microbial and invertebrate action (Wiegert and Evans 1964). Consequently, it would be predicted that the rate of decay would increase with increased temperature and humidity. This hypothesis is consistent with the small litter pool in humid tropical forests compared with the relatively large pool in cool temperate forests. As humidity is not simulated, the ratio of soil moisture to field saturation (FACTOR) is used as an index of moisture conditions in the model. The actual rate is defined as

DECAY = 0.0025*KPREV+0.00020*FACTOR*TEMP
DECAY = DECAY*PTOTAL/3000.

where KPREV defines whether on that day rain fell(=1) or not(=0) and PTOTAL is the toal amount of pasture dry matter (kg ha^{-1}).

During the tuning and validation stages (which are discussed later) it became clear that either the structure of the model was in great error and/or that the decay rates of pastures containing a large amount of dry matter must be greater than pastures with little dry matter. Consequently, the above effect of total pasture was introduced. If this procedure was not adopted, the predictions of the fraction of green in the pasture were over-estimated at low and under-estimated at high pasture availabilities.

Competition

It is clear from several studies (Bryan 1967; Mears 1973) that in the area under study large changes in botanical composition can result from management changes. The most usual method is by the application of fertilizer, however, grazing pressure can have a significant influence on botanical composition. These changes may result in large differences in the productivity of pasture. Because of the potential importance of botanical composition changes, an attempt has been made to include plant competition and the subsequent botanical composition changes in the model.

The competitive advantage of one species over another in a pasture sward will be the result of increased efficiency in at least one process, for example a higher efficiency of water capture, drought tolerance, phosphorus utilization or light interception. Consequently, an attempt to simulate competition based on a model of the various mechanisms operating, would almost certainly be very complex. Thus, even if it were possible, such an approach would introduce an imbalance in the structure of the model which would not be warranted. For this reason the following empirical approach was adopted.

In the model, the change in the percentage of ground cover (PERCEN) occupied by each species is a function of its own growth rate, with a weighting for the different species according to their phenology and the soil nitrogen levels. The maximum (CVRMAX) and minimum (CVRMIN) amounts of ground cover that each species can occupy are .97 and .01. If such a provision were not made, a species could be entirely removed from a sward with no chance of re-entry. The phenological weightings are obviously arbitrary but were decided after reference to the work of Younger (1961), Gartner (1966; 1969) and Cassidy (1971) and after consultation with agronomists at Grafton, Wollongbar and Brisbane who have some familiarity with these species and who were aware of how the competition sub-model operates. The final values were determined during the tuning stage of the model development.

Total growth (TGROTH, kg $ha^{-1}d^{-1}$) of each paddock and the contribution of each species to that growth is calculated. If the fraction of the total growth contributed by a species exceeds the fractional amount of ground cover of that species, it is defined to be "actively growing" and its proportion of ground cover will increase. The actual increase is dependent on the species, soil nitrogen level, the absolute value of TGROTH and how close the PERCEN value for the species is to its CVRMAX value. If TGROTH is large, more rapid pasture composition changes can ensue. If PERCEN is near CVRMAX the rate of change decreases - if this were not done, then attaining a stable mixture of grasses in the simulated sward would be well nigh impossible.

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Chapter 4

THE ANIMAL SUB-MODEL

The animal sub-model is physically larger and uses more computing time than either the climate generator or pasture sub-model because a large range of options have been included in it. Six classes of animal are defined and any number of any of these classes can "graze" a paddock concurrently - with the provision that equal numbers of lactating cows and suckling calves must be maintained. Varying amounts of grain and/or a conserved roughage (silage or hay) can be fed at any time. Animals belong to one of the following classes :

Class Number	Description
1	Steers
2	Dry non-pregnant cows
3	Dry pregnant cows
4	Lactating non-pregnant cows
5	Lactating pregnant cows
6	Suckling calves

The animal classes are not further divided into cohorts as has been done in other models involving the breeding animal (D.H. White pers. comm.). Such a division would have been a useful means of following groups of, for example, calves through the system. It would also produce a more realistic distribution of animals within a class. However, the animal sub-model was already so complex, relative to the other sections, that further development seemed unjustified.

The pasture sub-model was composed of six pools within each pasture species so that the ageing of pasture could be simulated. This is mainly important from the animal consumption and utilization point of view; it would make little difference to the simulated production of pasture whether one or four green pools exist but ageing can have a large effect on the nutritive value of some of the tropical pasture species being considered in the model (Jeffery and Holder 1971).

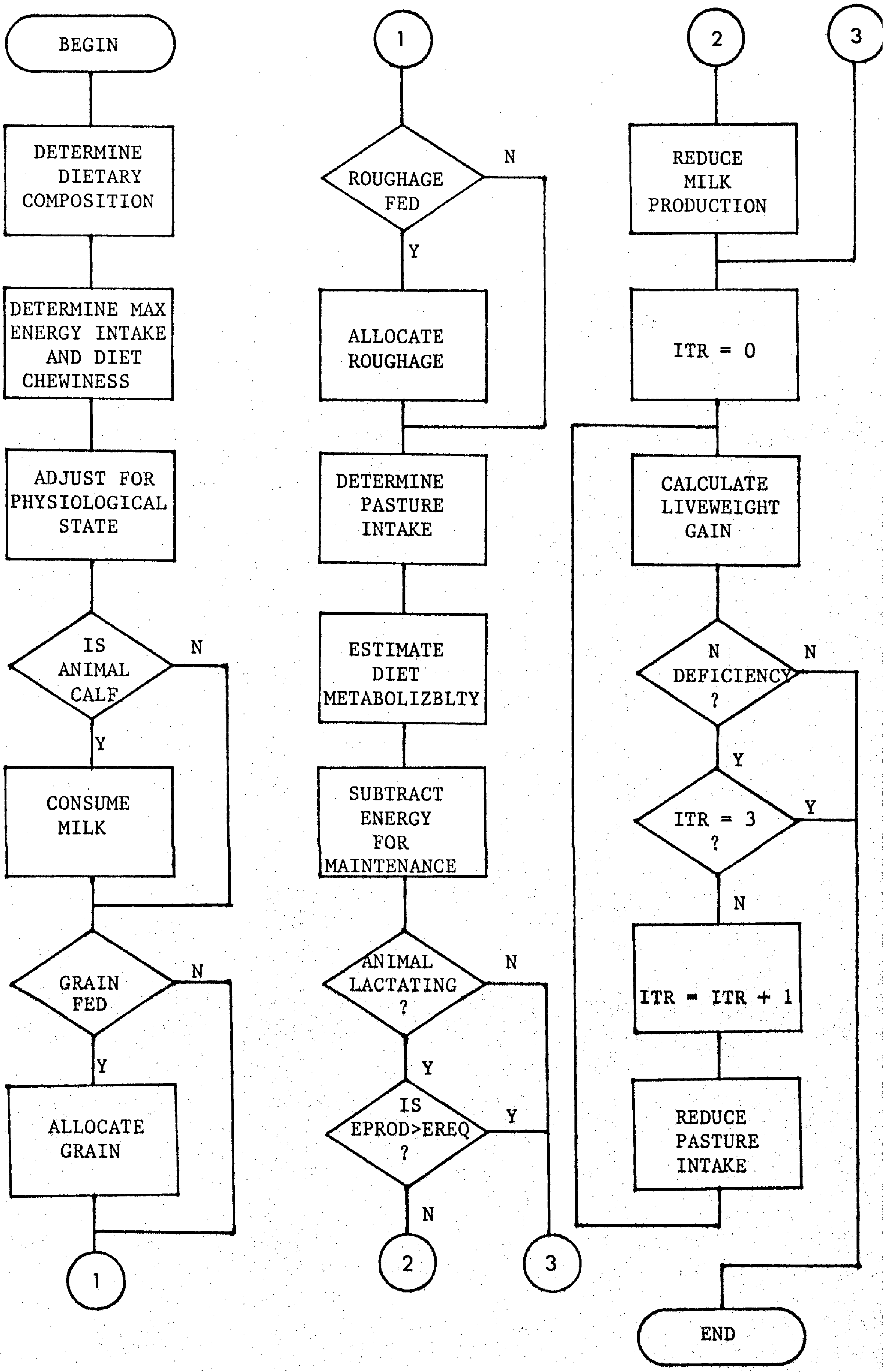

Figure 4.1 - Flow-chart of the feed utilization routine

A flow-chart of the feed consumption and utilization section of the animal sub-model is shown in Figure 4.1. This section is controlled by subroutine EATUP with SELECT being used to determine the botanical composition of the diet selected. If lactating cows are grazing then a call is made to subroutine MILK. A number of other subprograms are associated with the animal sub-model, but their function is largely bookkeeping. The other subroutines and functions manage breeding, calving and weaning and any associated changes of paddock.

Diet Selection

The botanical composition of the diet selected is determined by three responses : (i) the greater the amount of a component on offer, the greater the consumption of that component, (ii) as material passes from pool to pool its relative attractiveness decreases and (iii) some species are preferred to others. Stated in these general terms the three assumptions will apply over a wide range of circumstances, although under some conditions animals may select for dry roughage in preference to lush pasture. However, the quantification of these assumptions is far from straightforward. The pasture pools are conceptual rather than physically identifiable components of the pasture, and hence, even given unlimited resources, it would be impossible to measure the relative attractiveness of the different pasture pools.

Arnold (1964) concluded that young green material is selected preferentially by sheep and cattle and that leaves are preferred to stems. Moir (1960) noted the selection of short green material on both carpet grass and paspalum dominant swards. The more detailed studies of Stobbs (1973a, 1973b) on the pasture intake of several other tropical pasture species has implicated sward geometry; the notion of sward geometry was not included in the model because it would have introduced a degree of complexity to the animal sub-model that was not matched in the other sections of the model. It is well known (Arnold 1964; Van Dyne and Heady 1965; Galt et al. 1969) that cattle can show a preference for particular pasture species, and this was the last concept to be incorporated into the dietary selection routine of the model.

No published data exist that would allow any but the crudest estimates to be made of the dietary composition of cattle grazing pastures on the north coast. Estimates of the relative preferences of cattle for the different pasture species were made after discussions with research workers at CSIRO, Cunningham Laboratory, Brisbane and the N.S.W. Department of Agriculture, Agricultural Research Stations at Wollongbar and Grafton. The current estimates are set so that there is no selectivity between the grasses but clover is preferred to the grasses. The actual preference ratings given are held in the array PREF and can be found in the DATA statements at the commencement of subroutine SELECT (Appendix C). An example follows of how the dietary composition of an animal grazing the sward presented in Table 4.1 is calculated.

Table 4.1 - Botanical composition of an hypothetical sward (kg ha^{-1})

Pool		Carpet grass	Paspalum	Kikuyu	White clover
Green	1	40	20	130	10
"	2	30	40	130	20
"	3	50	30	140	15
"	4	60	40	140	20
Dry	5	170	100	330	90
Inflorescence	6	10	20	0	0

Each of the values in Table 4.1 is multiplied by its respective PREF value and the result stored in array DIET. The DIET values for each row of the table are summed and stored in array COMPON.

Considering only the consumption from pasture pool 1, the program will calculate

```
DIET(1,1) = 40*0.95   (amount of species * PREF)
DIET(1,2) = 20*0.95
DIET(1,3) = 130*0.95
DIET(1,4) = 10*1.15
COMPON(1) = DIET(1,1)+DIET(1,2)+DIET(1,3)+DIET(1,4)
          = 192
```

The values in the remaining locations 2 to 6 of COMPON would be 213, 227, 251, 674 and 29 respectively.

The following coding is used to determine dietary composition

```
      FRACTN  = 1.0
      DO 50 I = 1,6
      COMP(I) = FRACTN*CELECT(COMPON(I),BASE(I))
   50 FRACTN  = FRACTN - COMP(I)
```

where the i-th entry in COMP determines the fraction of the diet that will be consumed from the i-th pasture pool and CELECT is a statement function which is demonstrated in Figure 4.2; the purpose of parameter BASE is also demonstrated in the same figure. The numerical values of the array BASE are 50, 50, 50, 50, 400 and 400.

The value for COMP(1) will thus be .142, the values for the remaining locations of COMP being .140, .127, .119, .129 and 0. This will leave FRACTN with a value of .343. Because FRACTN is greater than 0 the values of all COMP are increased by a factor 1.0/(1.0-0.343)=1.522. Hence the entries in COMP become .216, .213, .193, .181, .196 and 0; these values sum to 1, within rounding errors.

The next step is the determination of the proportion of each species within a pool that is consumed. This is determined as the product of the respective DIET and COMP values divided by the respective COMPON value. Thus the fraction of the diet (FRCINT) composed of species J, pool I is

```
FRCINT(I,J) = COMP(I)*DIET(I,J)/COMPON(I)
```

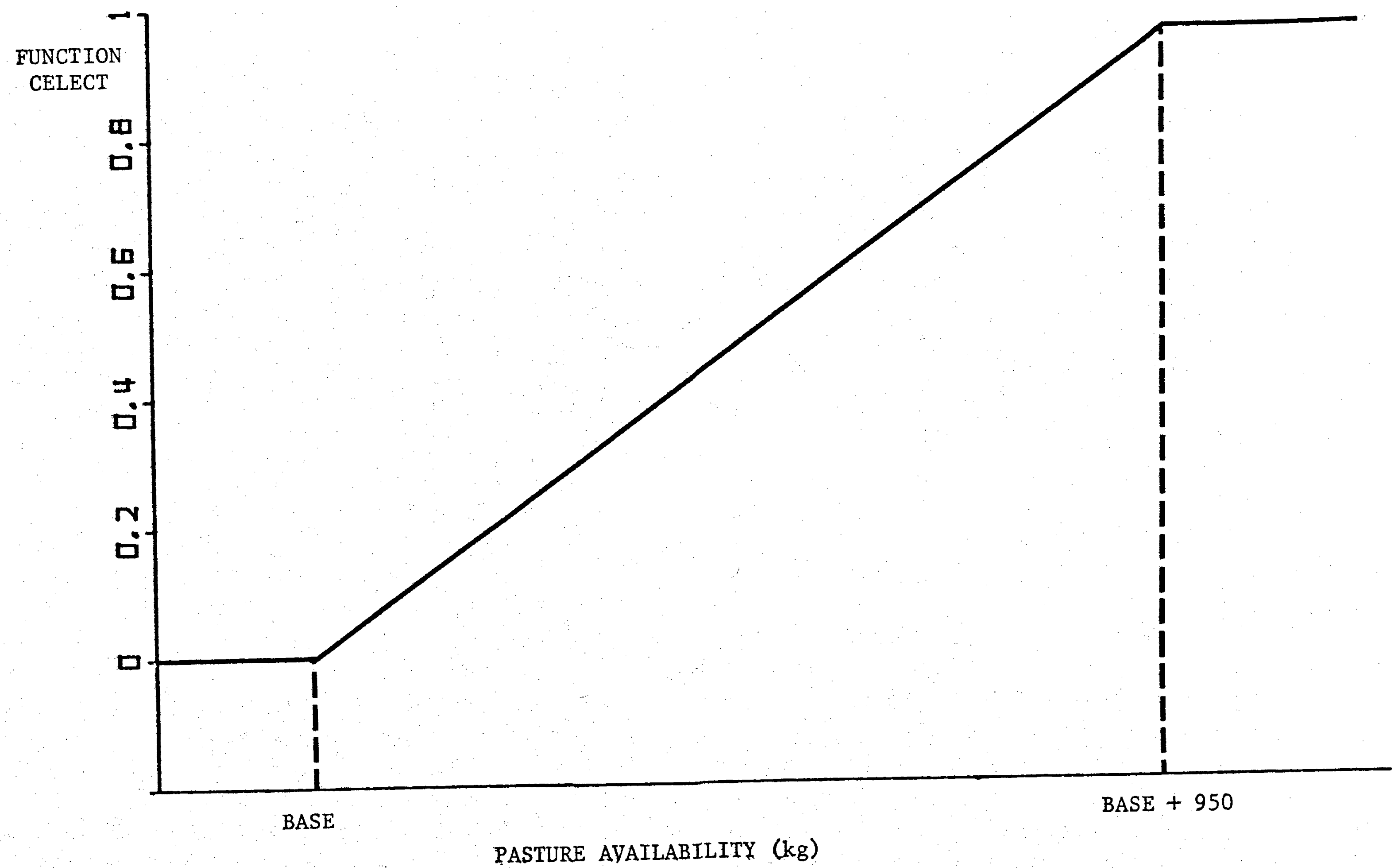

Figure 4.2 - The statement function CELECT which is used in the determination of the botanical composition of the diet selected

From the above example the values of FRCINT are presented in Table 4.2.

Table 4.2 - Values of FRCINT calculated from the sward given in Table 4.1.

Pool	Carpet grass	Paspalum	Kikuyu	White clover
1	.043	.021	.139	.013
2	.029	.038	.124	.023
3	.040	.024	.113	.015
4	.041	.027	.096	.017
5	.047	.028	.091	.030
6	0	0	0	0

In Table 4.3 the botanical composition of the hypothetical sward is again presented but this time as fractions of the total weight of pasture on offer. A comparison of Table 4.2 and 4.3 will demonstrate that the selection algorithm is working in the intended manner; within a pool, selection is for the greater amounts on offer, material in pool 1 is preferred to that in pool 2 and so on, there is positive selection for clover (compare entries in pool 5, clover vs paspalum).

Table 4.3 - Botanical composition (in fractions) of hypothetical sward in Table 4.1.

Pool	Carpet grass	Paspalum	Kikuyu	White clover
1	.018	.012	.080	.006
2	.018	.024	.080	.012
3	.031	.018	.086	.009
4	.037	.024	.086	.012
5	.104	.061	.202	.055
6	.006	.012	0	0

The three assumptions on which the dietary selection routine is based have all been used either singly or in various combinations in other models. A number of investigators have shown that as pasture availability increases so also does animal intake. Most frequently this was shown indirectly as, for example, an increase in liveweight gain as pasture availability increased. Clearly, in such a demonstration, assumptions are made about the calorific value of liveweight gain, composition of the diet selected and efficiencies of conversion; existing knowledge of the subject suggests that the assumptions are plausible and the conclusion that increased pasture availability results in an asymptotically increasing intake seems reasonable. Workers who have provided either direct or indirect evidence of such a relationship with cattle include Johnstone-Wallace and Kennedy (1944), Greenhalgh (1966), Hart (1972) and Mears (1973).

If FRACTN is greater than zero then the potential intake of the animals is reduced. The reduction is by a factor, AVAILF, which is defined as

AVAILF = AMAX1(0.70,1.0-FRACTN)

Within each species, an estimate is made of the dry matter digestibility, nitrogen content and "chewiness" of each pool. The estimates of digestibility were based on _in vitro_ digestibility estimates of plant components (Jeffery, unpub. data) plus the published data of Milford (1960), Minson (1973), Minson and Milford (1968) and Jeffery and Holder (1971). Nitrogen content of pasture is well known to alter with soil fertility. In particular, the application of nitrogen fertilizer will generally increase the nitrogen content of pasture (Gartner 1969; Mears 1973). In the model, the nitrogen content of consumed feed is linearly related to the actual soil nitrogen level, FERTAN, using a different relationship for each species. The maximum increase in nitrogen content of the pasture species as soil nitrogen increases from zero to its maximum level is presented in Table 4.4. These estimates of response to increased soil nitrogen level and the estimates of nitrogen content were based on herbage nitrogen data of the grasses presented by Mears (1973) who reported the nitrogen content of plucked samples obtained about 30 days after either 0 or 134 kg N ha^{-1} had been applied. It was assumed that the high nitrogen treatment resulted in the maximum herbage nitrogen content and that the soil had a base nitrogen fertility of .3 (i.e. FERTAN = .3). The concept of feed chewiness will be discussed in more detail later; it is a measure of the fibrosity or "bulk" of a diet.

Table 4.4 - Mean nitrogen content of the pasture species at two levels of soil nitrogen

Soil nitrogen	Carpet grass	Paspalum	Kikuyu	White clover
Minimum	0.96	1.83	1.08	3.00
Maximum	2.30	4.20	4.00	4.50

The actual estimates of dry matter digestibility, chewiness and nitrogen content at the lower soil nitrogen level for each component of each species can be found in DATA statements at the beginning of subroutine SELECT in arrays DMD, CHEW and PLANTN respectively (Appendix C). The digestibility (DIGEST) of the consumed feed is then calculated :

```
      DIGEST  = 0.0
      DO 10 I = 1,6
      DO 10 J = 1,4
   10 DIGEST  = DIGEST + FRCINT(I,J)*DMD(I,J)
```

In a similar way, the mean chewiness (FIBRE) and nitrogen content of the diet (DIETN) are calculated.

One weakness of the model is that it relies heavily on the selection routine described above and the development of this routine was constrained by a paucity of data and the existing conceptual framework of the model. Until the framework for a good understanding of dietary selection has been educed it seems likely that dietary selection routines will remain a weak link in whole-farm simulation models.

Determining Intake

Numerous factors have been demonstrated to affect ruminant intake; Conrad, Pratt and Hibbs (1964) reported that over 20 variables have been implicated. Examination of a few years' issues of the more prominent agricultural research journals offers convincing evidence that huge amounts of money have been spent on ruminant intake and digestibility studies. Despite this expenditure, little unifying theory exists.

About a decade ago several US workers (Conrad, Pratt and Hibbs (1964), Conrad (1966) and Montgomery and Baumgardt (1965a, 1965b) advanced a simplifying concept. They saw intake being initially restricted by the undigested residue or "bulk" of the diet - so that as digestibility increased (and hence, in general, bulk decreased) intake also increased (see Figure 4.3). With further increases in digestibility the point was reached at which the energy demand of the animal was satisfied. From this point on, if digestibility increased (and hence the utilizable energy per unit weight increased), feed intake decreased (Figure 4.3).

Troelsen and Bigsby (1964) and Chenost (1966) have indicated the importance of the fibre content of a feed in the determination of intake. More recently Balch (1971) suggested a more biologically meaningful method of measuring feed bulk and of how bulk may limit intake. Balch noted that the total eating and rumination time of a number of feeds was relatively constant. He suggested that by considering the total time spent eating and ruminating (chewing time) and the feed intake one could gain an idea of the "chewiness" of the feed (expressed in units of min kg^{-1}). Balch's suggestion that there is an upper limit to total chewing time which limits intake is a similar notion to that of Stobbs (1973a) who suggested that a grazing dairy cow will only take of the order of 36,000 bites per day.

In the model, intake is controlled by either energy demand being satisfied or the total "chewing time" being used. Several advantages were seen in this "limiting factor

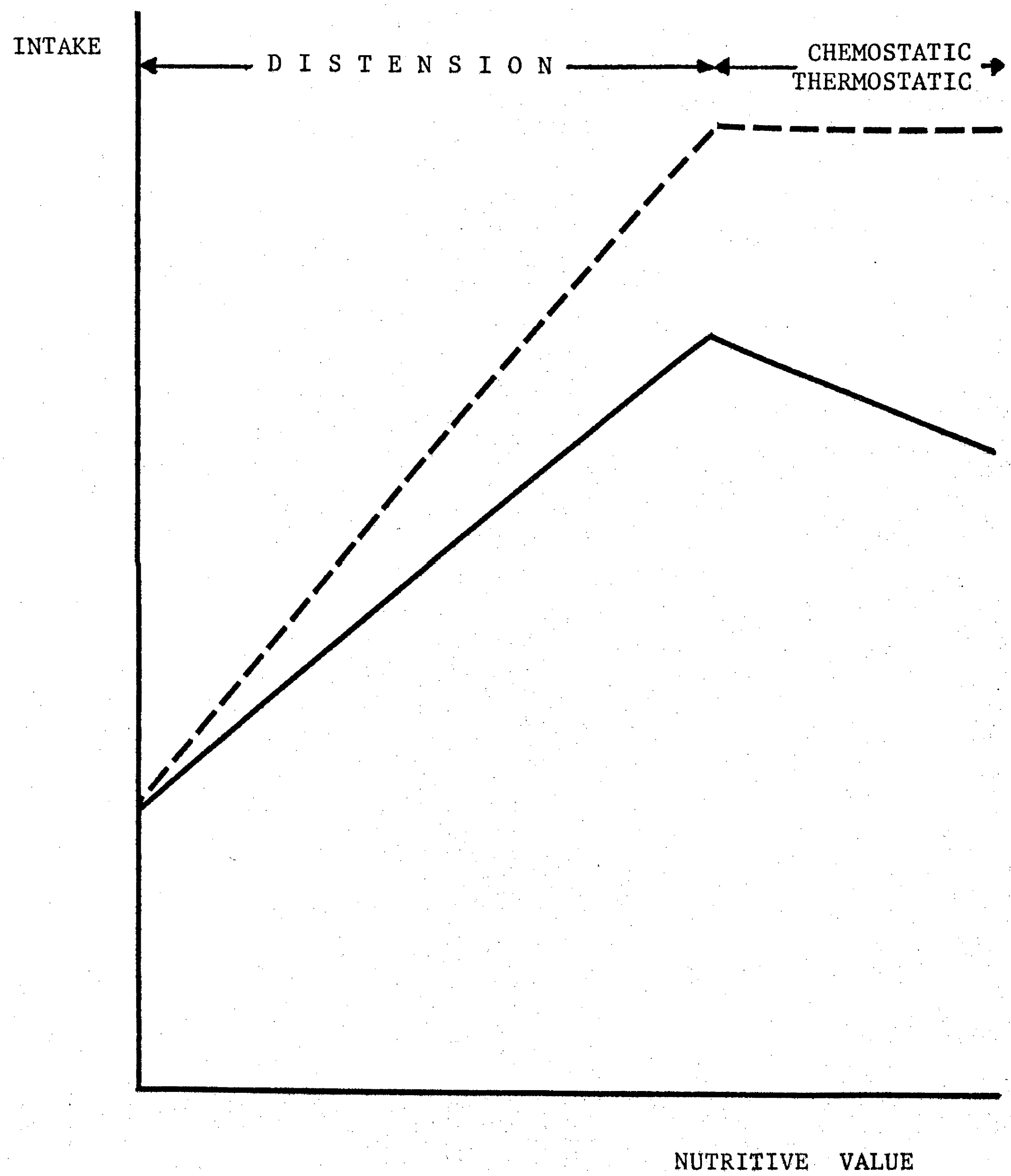

Figure 4.3 - Relationship proposed by Montgomery and Baumgardt (1965a) to describe the regulation of feed intake in cattle. Solid line represents dry matter intake and broken line represents energy intake

approach" as compared with the method (Freer et al. 1970; Vickery and Hedges 1972; Anway 1973) of taking potential intake to be inversely related to the digestibility of the consumed feed. The method used in this model is consistent with a theory whereas the method used by the previously cited authors is at least one step removed from causation (digestibility *per se* does not influence intake but rather the highly correlated variable, rate of passage). Therefore, the limiting factor approach is likely to yield a better understanding of the system. Also, the more conventional approach is less applicable to tropical feeds in which the intake/digestibility relationship is more variable than it is with temperate feeds (Jeffery and Holder 1971). A major advantage of the limiting factor approach is that mixed diets of say, grain and roughage, can easily be accommodated in the model, because, each different feed supplies some of the energy demand and uses some of the total chewing time. Hence, the difference between the daily energy demand (total chewing time) and that supplied (used) by the first feed remains to be supplied (used) by the second feed. The greatest disadvantage of the limiting factor approach is that estimates of energy demand or total chewing time are rare or non-existent whereas the relationships between intake and digestibility, particularly for temperate pasture species, have been investigated by a legion of authors.

Maximum daily metabolizable energy intake (ENGMAX, Mcal) is expressed as a function of weight (WT, kg). The coefficients vary for the different animal classes and are affected by physiological state but the general form of the relationship between ENGMAX and WT is

ENGMAX = A*WT**.75

The exponent of weight, .75, used in the above relation was chosen to be in line with the theoretical reasoning of Conrad (1966) and the empirically determined constants of Conrad, Pratt and Hibbs (1964). The values of the coefficient, A, are .24 (dry cows), .25 (steers) and .315 (calves). These estimates can be seen to be within the range of values extracted from, or derived from the literature and presented

Table 4.5 - Estimates of the coefficient, A, derived from literature in which metabolizable energy[a] intake (MEI, Mcal d^{-1}) has been related to weight (W, kg) by the following relation

$$MEI = A.W^{0.75}$$

Coefficient (A)	Class of animal	Description of feed	Reference
.26[b]	Steer	Dried grass	Blaxter and Wilson(1962)
.27	Steer	Fresh grass-Expt 1	Holmes and
.26[c]	Steer	Fresh grass-Expt 2	Lang(1963)
.20	Yearling	Chopped hay	Buchman and
.24	Yearling	Pelleted hay	Hemken(1964)
.22	Calf	Chopped hay	
.23	Calf	Pelleted hay	
.20	Heifer	Hay & corn	Montgomery & Baumgardt (1965a)
.23	Heifer	Hay & corn	Ibid(1965b)
.34[d]	Steer	Dried grass	Blaxter, Wainman and Davidson(1966)
.23	Cow	long dried grass	Campling and Freer(1966)
.29[e]	Cow	Hay & concentrate (Expt 6)	Campling and Murdoch(1966)
.26[f]	Steer	Hay/concentrate mix	Boling *et al.* (1967)
.29	Thin cow	Hay/concentrate	Bines, Suzuki & Balch(1969)
.25	Steer, weight=114 kg		McCullough
.25	Steer, weight=159 kg		(1969)
.26	Steer, weight=205 kg		
.26	Steer, weight=250 kg		
.24	Steer, weight=295 kg		
.20	Steer, weight=341 kg		

[a] calculated assuming metabolizable energy = .82 x digestibile energy

[b] steers 18 months old; weight not given but assumed to be within 300-500 kg range

[c] diet digestibility assumed to be 75%

[d] steers 30 months old; weight not given but assumed to be within 500-650 kg range

[e] assuming concentrate digestibility to be 75%

[f] assuming ME to net energy efficiency of .60

in Table 4.5. When the values in Table 4.5 were being derived and the weight of the animals was not stated (e.g. Buchman and Hemken 1964), then the average of one or more estimates was used. If a weight range was given (e.g. McCullough 1969), the mean of the limits of the range was used to calculate the coefficient.

There is no guarantee, that in some of the cases considered in Table 4.5, intake was not limited by feed bulk - if this were the case the coefficient would be biassed downwards. The digestibility of the feeds used in the study of Buchman and Hemken (1964) were all below 62% - a level at which intake may well have been limited by feed bulk.

The second variable estimated in the determination of intake is the total chewing time (rumination and prehension) of the animal (FIBMAX). Apart from the publication of Balch (1971), I could not locate any further information on this subject. Consequently, the algebraic form of the function used to predict FIBMAX could be in considerable error.

The function used to calculate FIBMAX implies that the chewing time of a steer weighing 350 kg will be 424 min d^{-1}, whereas a 600 kg steer will be capable of chewing for 553 min. It would be most unlikely that differences, if they exist, would be of this magnitude. The alternative and more correct way to represent the different efficiencies of chewing would be to make the chewing time per kg of a feed a function of animal weight. Thus, in the above case, both the 350 and 600 kg animal may be considered to have 500 min of chewing time, but the 350 kg steer may take 80 min kg^{-1} to chew a feed to a sufficiently fine state so that it passes through the reticulo-omasal orifice whereas 60 min kg^{-1} may be a more appropriate time for the 600 kg steers. Hence, in this example, the limit imposed on intake by the chewiness of the feed would be 500/80 = 6.3 kg for the 350 kg animal and 500/60 = 8.3 kg for the 600 kg animal. Either the approach used in the model in which FIBMAX is a function of weight or the approach just described could be "tuned" to give similar answers.

FIBMAX is described by a function of the form,

FIBMAX = A + B*WT*EXP(-C*WT)

where A, B and C are positive constants and WT is liveweight. There are few data with which the form of this function can be validated. The function has been graphed against data obtained by McCullough (1969) when he fed a high roughage diet of 61% energy digestibility. It would thus seem likely that the intake of cattle fed this diet was limited by bulk (Conrad, Pratt and Hibbs 1964). The graph in Figure 4.4 only demonstrates that the curve selected has a reasonable shape over the weight range 114 to 341 kg.

Having calculated ENGMAX and FIBMAX values, adjustments for physiological state are made. If grain or a roughage is fed, the metabolizable energy it provides is subtracted from ENGMAX and the chewing time involved is subtracted from FIBMAX. Pasture intake (PASINT, kg) is then calculated as

PASINT = AMIN1 (FIBMAX/FIBRE,ENGMAX/ENERGY)

where ENERGY is the metabolizable energy content of the selected pasture and FIBRE is the mean chewing time per kg of the selected pasture. AMIN1 is a Fortran IV function which selects the minimum of any number of floating point arguments.

Adjusting Intake for Physiological State

Lactation and pregnancy are assumed to affect intake. Lactation is taken to increase and pregnancy to decrease energy demand and chewing time. The effects of lactation and pregnancy depend on the potential milk production of the cow and on the stage of pregnancy, respectively.

A number of studies with dairy cows have indicated that lactation will increase intake. A simplistic explanation is "the stimulatory effect of lactation". If the increase in intake were due simply to the effect of lactation then an on/off relationship in which intake increased by a fixed amount when the animal was lactating, or an increase in intake that is a function of the amount of milk produced

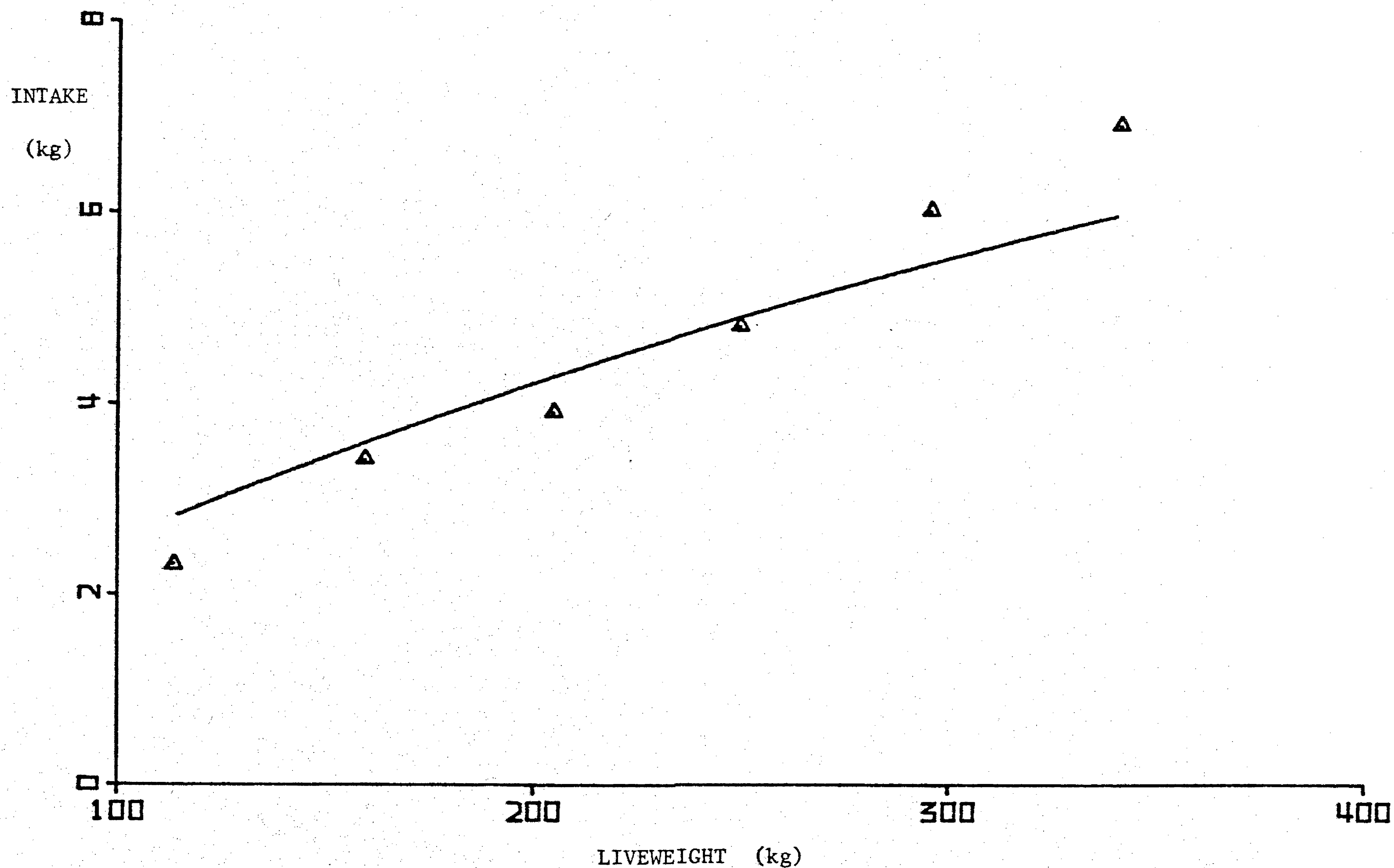

Figure 4.4 - Feed intake of an all-roughage diet observed by McCullough (1969). Unbroken line represents the predictions of intake from the FIBMAX function in the model if the diet is assumed to have a FIBRE value of 76. See text for details

might be expected. In fact, neither of these effects are observed but rather intake increases after calving but maximizes some time after the peak milk yield is attained (Hutton 1963; Johnson et al. 1966; Marsh, Curran and Campling 1971). The reason for this lag is not clear. In the model, potential intake varies directly with potential milk yield - this is recognised as being inaccurate because the lag in the intake peak compared to the milk yield peak is not simulated but it was thought to be a reasonable first approximation.

Several attempts have been made to measure the increase in intake that accompanies lactation. The techniques used are not always convincing and, indeed, it would be most difficult to design and conduct an experiment which allowed this comparision to be unequivocally made. In general, to demonstrate the effect of lactation on intake, then the consumption of two groups of cows of similar age must be measured, one group composed of lactating cows the other composed of non-lactating cows frequently of different bodyweight,usually gaining rather than losing weight and often in better condition (e.g. Jordan et al. 1973). It is virtually impossible to get two groups of animals eating the same diet in which body condition and rate of liveweight change is similar between the groups but where one group is composed of lactating and the other non-lactating cows. Yet, to determine the effect of lactation alone on intake it is necessary to compare groups which differ only in their lactational status. The problem arises because the lactational physiology that has evolved in the bovine is such that body tissue is often sacrificed in early lactation when cows are consuming a diet that would normally promote liveweight gain. Unravelling the direct effect only of pregnancy on intake would also be a most difficult task for reasons similar to those advanced when discussing the effect of lactation on intake.

Despite the difficulties, some interpretation of the effects of lactation and pregnanacy must be made. A sampling of the average values reported in the literature (Table 4.6) led to the following estimates being used in the model :

maximum increase of intake associated with lactation is 40%, maximum decrease of intake associated with pregnancy is 10%. It is realized that these values could be in considerable error.

Table 4.6 - Reported and derived estimates of the effect of lactation and pregnancy on dry matter intake.

Physiological state	Change in intake (%)	Reference
Lactation	+28	Elliot, Fokkema and French (1961)
Lactation	+17, wk 1-12	Hutton (1963)
	+38, wk 13-24	
	+52, wk 25-36	
	+47, all lactation	
Lactation	+14, concentrate + hay	Campling (1966)
	+ 8, concentrate	
Late pregnancy	-10, concentrate + hay	
Pregnancy (last 6 wk)	- 7, sorghum silage	Lamberth (1969)
	- 9, lucerne chaff	
Pregnancy (last 2 wk)	-12, hay + silage	Jordon *et al.* (1973)

The fractional increase in intake resulting from lactation is defined as

FLACT = POTYLD/YLDMAX * 0.4

where POTYLD is the potential yield of milk on that day of lactation and YLDMAX the maximum potential milk yield for that lactation. The fractional decrease in intake as a result of pregnancy is defined to be a function of the number of days pregnant (NDPREG). This decrease, FPREG, is calculated as follows,

```
FPREG = 1.0-(NDPREG-240.)*0.0025
IF(NDPREG.LE.240)FPREG=0.0
```

Thus, if a non-pregnant, non-lactating cow weighing 500kg consumed 7kg of a particular feed then the intake, PASINT, of a 500kg lactating cow which had a YLDMAX value of 10kg but had a potential daily yield of 6kg milk, would be calculated as follows

PASINT = 7.0 * (1.0 + 0.4*6/10)
= 7.0 * 1.24
= 8.7

The Diet if more than One Feed is on Offer

If a simulation model allows a number of feeds to be offered to an animal then the simplest distributional procedure is to establish an order of allocation. The procedure followed in the model distinguishes between calves and other animals (classes 1-5). Cattle in classes 1 to 5 have first access to any grain or hay. If some remains, the calves have access to it. Pasture is only consumed if either the FIBMAX or ENGMAX values are not zero following allocation of grain and/or hay. Calves consume all the milk produced by the cows unless it exceeds the calves' ENGMAX limit. Calves then have access to any remaining grain or hay and, finally, if their ENGMAX and FIBMAX values are greater than zero, the calves will consume some pasture.

If sufficient grain is fed to satisfy the energy demand of animals in classes 1 to 5 then their total diet is composed of grain. If not, allocation is proportional to energy demand. If insufficient hay or silage is provided to meet the potential hay intake, allocation is proportional to potential hay intake.

Diet Metabolizability and Energy Partitioning

The division of consumed energy within the animal largely follows the system outlined by ARC (1965). This system involves the partitioning of metabolizable energy for various physiological functions, each with an efficiency which may vary. The first stage in the partitioning of energy intake is calculation of diet metabolizability, i.e. the ratio of metabolizable : gross energy in the diet.

Metabolizable energy (ME) is assumed to be .82 times digestible energy (Blaxter 1964). The calculation of pasture digestibility has been described; grain digestibility is held in variable DIGRN and is set at .80 and roughage digestibility, DIGHY, is initially set at .65 - the values of both these variables can be altered within the program. Total diet metabolizability, QM, is then calculated as the mean metabolizability of the dietary components, weighted for dry matter intake. ME intake is calculated as QM*EDM*(dry matter intake), where EDM is the energy content of dry matter - 4.39 Mcal kg^{-1}(Jeffery 1971a). The intake of ME is held in variable EMET.

The fasting heat production per unit of metabolic weight (liveweight raised to the power 0.73, $W^{.73}$) of young cattle can be almost double that of older cattle (ARC 1965). Because the age of animals is not kept in the model, the age correction for the fasting heat metabolism was made indirectly, through animal liveweight (WT). Hence, fasting heat production (FASTHP, kcal) per $W^{.73}$ (kg) is calculated from

FASTHP = 75.5 + 80.5*EXP(-.004*WT)

EMAINT = FASTHP*(WT**0.73)/1000

EMAINT is then divided by the efficiency of utilization of ME for maintenance, EFFICM, which is derived from the formula proposed by ARC (1965) :

EFFICM = 0.546 + 0.30*QM

An EFFICM value of .75 is assumed for calves, which implies a diet digestibility of 83%. In the last month of pregnancy the maintenance requirements are raised by 20% (ARC 1965).

The energy costs for horizontal locomotion and vertical ascent have been estimated as 0.48 and 6.8 cal $kg^{-1}m^{-1}$ for cattle and horses respectively (ARC 1965). No estimates of the energy cost of vertical ascent for large animals other than the horse were presented. Because walking typically involves a mixture of horizontal progression and vertical ascent, an intermediate value of 0.55 cal $kg^{-1}m^{-1}$ was chosen. If it is assumed that no energy cost is involved in descent (ARC 1965) then this value implies that the animals are walking on terrain with an average slope of 1:45.

Larkin (1954) provided estimates of the distance walked by grazing cattle on tropical pastures. The distance walked (WALK, m) decreased as pasture availability (PTOTAL, kg ha^{-1}) increased. Larkin's estimates were low (cf. Hancock 1953) and somewhat higher predictions are obtained from the relationship used in the model :

WALK = 2400 + 3200*EXP(-.0025*PTOTAL)

EWALK = WALK*0.55*WT*1.0E-6

The efficiency of utilization of ME for walking (EFFICW) is between that of maintenance and that of fattening (ARC 1965). An arbitrary choice of EFFICW = 0.8*EFFICM was made.

The difference between the consumed ME and that used for maintenance and walking is now calculated. This value, EPROD, is the energy remaining for production - it can, of course, be a negative quantity in which case the animal loses weight. EPROD is calculated as

EPROD = EMET - EMAINT - EWALK

If EPROD is greater than zero then the level of feeding is greater than one, in which case ARC (1965) argues a depression in the availability of ME should result. The depression (DEPRES) is calculated following the method outlined by ARC (1965).

If EPROD is equal to some value other than zero then liveweight is likely to be added or removed from the animal. Hence, an estimate of the calorific value of weight gain (CALVWG, Mcal kg^{-1}) is required. The estimate is obtained from a regression which was calculated from the predictions of a series of five curves presented by ARC (1965). The curves represented different weight classes but the following curve effectively combines the five curves

CALVWG = 1.425 + 0.00365*WT + 0.231*ABS(EPROD)*EFFICF
+ 0.00011*WT*ABS(EPROD)*EFFICF

where ABS is the Fortran function which obtains the absolute value of the argument and EFFICF is the efficiency of using ME for fattening. The calorific value of the weight gain of a 400 kg steer that retained 3.0 Mcal energy, would be 3.71 Mcal kg^{-1}. The prediction for a 400 kg animal from the equation of ARC (1965) is 3.74 Mcal kg^{-1}.

The efficiency of ME use for fattening is set at .85 if the animal loses weight or, if a weight gain results, it is calculated (Blaxter 1964) as

EFFICF = 0.81*QM + 0.03

Hence, weight change (WTGAIN) is calculated as

WTGAIN = EPROD*EFFICF/CALVWG

The preceding description of energy partitioning has ignored any effect of either lactation or dietary protein deficiency. These two aspects are considered below.

Lactation

Few attempts have been made to model bovine milk production (Crabtree 1970, 1972; Sewell et al. 1974). Crabtree (1970) did not use any method of energy partitioning but rather supplied the energy needs which were defined from a "standard lactation curve", hence, liveweight remained constant. Crabtree recognised that this approach restricted the system exploration that could be done with the model. The later model of Crabtree was also based on standard lactation curves and also did not allow for liveweight change during lactation. Feed allocation in his later model was determined from a linear programming subroutine which determined the feeding strategy that maximized net revenue (difference between milk sales and feed costs). Both of these models placed a greater emphasis on the economic evaluation of different systems than is being considered in this model. Consequently, less effort was put into the biological aspects of Crabtree's models.

Sewell et al. (1974) briefly described the construction of a simulation model of milk production. As in the models of Crabtree, the partitioning of energy to lactation and liveweight change was not decided dynamically; instead a pre-defined pattern of weight change was followed and excess energy went to milk production. For the same reasons as those recognized by Crabtree, the reality and applicability of such a model is limited.

Prior to constructing the lactation section of the model it was decided that it should incorporate the following four features :

(i) a poor diet on one day should depress production for that day,

(ii) continued poor diets should decrease a cow's potential milk production,

(iii) if an animal is changed from a poor to a good diet its milk production should increase, and

(iv) either positive or negative liveweight changes should be possible.

These features were included in the lactation routine for beef cattle because ample evidence exists that they occur in dairy cattle. Although the extent of some of the changes may be different in beef cattle, there is no reason to believe that similar effects do not occur. The model of Crabtree (1970) did not incorporate features (i), (ii), (iii) or (iv) and those of Crabtree (1972) and Sewell <u>et al</u>. (1974) did not include features (ii) or (iv). In the absence of a developed model or theory on energy partitioning in lactation, the following approach was followed.

At calving, the potential milk production curve is defined based on the function proposed by Wood (1967). This curve defines potential milk production (POTYLD, kg) in terms of the day of lactation (NDSUCK) and three parameters, AWOOD, BWOOD and CWOOD :

POTYLD = AWOOD*(NDSUCK**BWOOD)*EXP(-CWOOD*NDSUCK)

AWOOD is a "scaling parameter" whilst BWOOD and CWOOD are both "shape parameters". In general, these latter two parameters would be constants and AWOOD may be calculated as a function of cow weight, lactation number, breed and the immediately preceding plane of nutrition. In the model, AWOOD is simply defined as a function of weight and a variable, BREED, which can be varied depending on the milk producing ability of the breed of cattle being considered:

AWOOD = 1.0 - 1.25*EXP(-.005365*WT)

AWOOD = AWOOD*BREED

For typical beef breeds a value of about 2.5 is envisaged for the variable BREED. Approximate values of CWOOD and BWOOD

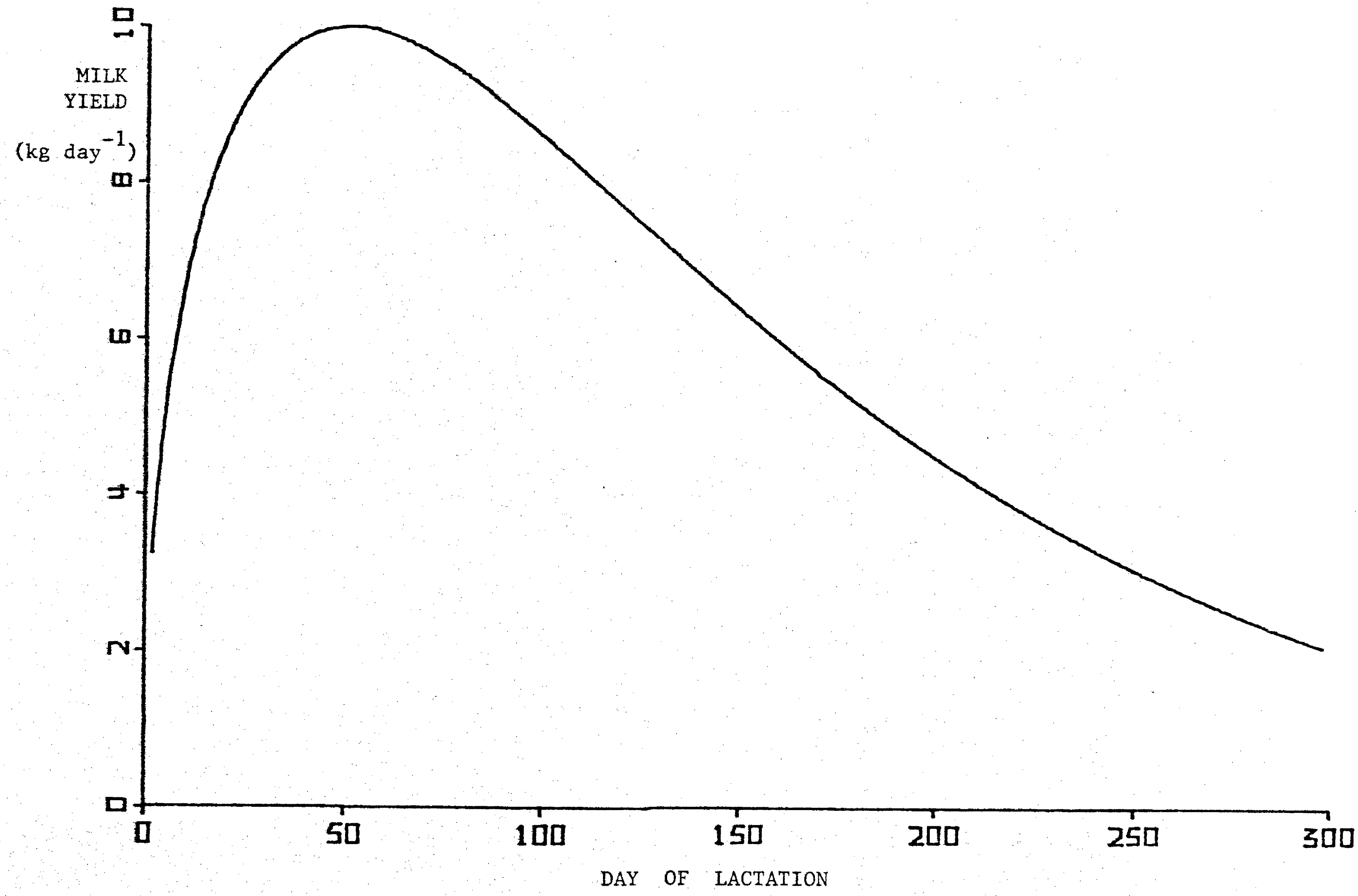

Figure 4.5 – The potential milk production of a cow giving a maximum yield of 10kg on day 50

that produce a reasonable milk production curve are CWOOD = 0.01 and BWOOD = 0.5. Thus the day at which maximum yield occurs (TMAX) is defined as

TMAX = BWOOD/CWOOD

= 50

and maximum yield (YLDMAX, kg) will be defined as

YLDMAX = AWOOD*BREED*((BWOOD/CWOOD)**BWOOD)*EXP(-BWOOD)

The shape of the POTYLD curve for a cow weighing 550kg with BREED = 2.5 is presented in Figure 4.5.

Each day, the potential milk yield (POTYLD) is calculated. The ME required (EREQ) to produce POTYLD is determined assuming that the efficiency of utilization of ME for lactation (EFFICL) is EFFICL=.5+.3*QM. The energy content of milk (ECMILK) is defined to be .76 Mcal kg^{-1} (ARC 1965). Thus,

EREQ = POTYLD*ECMILK/EFFICL

If EREQ is less than or equals EPROD then the milk production equals POLTYLD and any remaining ME is used for liveweight gain. If EREQ is greater than EPROD then a decrease in milk yield from POTYLD occurs and, if necessary, body tissue is mobilized to supply additional ME for milk production.

When EREQ exceeds EPROD the difference (DIFF) is calculated and the actual milk yield (ACTMLK) defined as a function of POTYLD and DIFF :

DIFF = EREQ - EPROD

REDUCN = 1.0-EXP(-0.008*DIFF**2)

REDUCN = AMAX1(REDUCN, 0.5)

ACTMLK = POTYLD*REDUCN

If EPROD cannot provide sufficient ME for the production of ACTMLK kg of milk then body tissue is used at an efficiency of .85. Alternatively, if the lowered milk production results in EPROD exceeding EREQ then the excess ME is converted to body tissue in the previously described fashion.

If EREQ exceeds the initially calculated value of EPROD then the scaling parameter, AWOOD, of the potential milk production curve is reduced. This reduction is not nearly as large as is the reduction in actual milk production but will have a significant effect if the animal is kept on a poor quality diet. The Fortran statement to achieve the reduction in potential yield is

```
AWOOD = AWOOD*(0.99 + REDUCN*0.01)
```

Protein Deficiency

The protein content of some of the pasture species on the north coast of NSW is low enough to limit the production of cows in early lactation and fast growing animals (Jeffery and Holder 1971). Because of the potential importance of such limitations, the protein consumption and requirements of all animals are calculated. If the consumption exceeds requirements then no limitation on intake occurs, however, if the reverse occurs, intake is reduced by three iterations unless, during iteration, consumption exceeds requirements.

Protein requirements are calculated from the determined protein content of tissue and milk produced. Estimates were obtained from ARC (1965). The gain in nitrogen deposited in the hair (HAIRN, g d^{-1}) is defined as

```
HAIRN = 0.02*WT**0.73
```

Endogenous nitrogen loss (ENDOGN, g d^{-1}) is predicted from the formula

```
ENDOGN = (0.12 + 0.186*EXP(-0.015*WT))*WT**0.73
```

and metabolic faecal nitrogen loss (FECALN, g d^{-1}) is a function of dry matter intake (DMI, kg) :

```
FECALN = 5.0*DMI
```

If, from energetic considerations, a liveweight change is predicted then the nitrogen content will be GAINN (g per kg liveweight change)

```
GAINN = 25.0*WTGAIN
```

where WTGAIN is the liveweight change (kg). The nitrogen loss from milk (DAIRYN, g d^{-1}) is calculated as a function of daily milk production (ACTMLK, kg)

```
DAIRYN = 7.2*ACTMLK
```

Hence, total daily nitrogen requirement (TOTNRQ, g) is calculated as

TOTNRQ = HAIRN + ENDOGN + FECALN + GAINN + DAIRYN

TOTNRQ can be expressed as the daily requirement (TOTPRQ) of digestible crude protein (DCP) by multiplying TOTNRQ by the protein-nitrogen conversion factor (PRNC = 6.25) and dividing by the biological value (BV = .75) of the DCP

TOTPRQ = TOTNRQ*PRNC/BV

The crude protein provided (PROPRV, g) by the diet is simply calculated as the sum of the products of the dietary constituents and their protein content. The mean crude protein (CP) percentage of the diet is calculated and then the digestible crude protein percentage of the diet is calculated using the conversion established by Jeffery (1971b) on some north coast pasture species:

DCP = -4.96 + 1.01*CP

The digestible crude protein (g) provided by the diet is then calculated as

DCP = DCP*DMI*10.0

If DCP exceeds TOTPRQ, then the production expected from energetic considerations ensues. However, if TOTPRQ exceeds DCP, pasture intake (PASINT) is decreased by an amount that depends on the size of the difference between TOTPRQ and DCP

PASINT = PASINT*(0.6 + 0.4*DCP/TOTPRQ)

The program now recalculates TOTPRQ, DCP and WTGAIN based on the reduced pasture intake. If DCP now exceeds TOTPRQ the program advances, otherwise PASINT is again reduced. After a maximum number of three such iterations the program will advance to the next section although DCP may not exceed TOTPRQ.

By this method large reductions in pasture intake can occur if protein is limiting production. Three examples, taken from a run of the model, demonstrating the effect of successive iterations on several variables are presented below

Iteration	Pasture intake (kg)	DCP supplied (g)	DCP required (g)	DCP deficit (g)
Initial	6.2	310	366	56
1	5.8	290	313	23
2	5.6	282	291	9
3	5.5	279	282	3
Initial	4.9	273	330	57
1	4.6	254	295	41
2	4.3	240	266	26
3	4.1	230	246	16
Initial	4.8	268	322	54
1	4.5	250	288	38
2	4.3	237	261	24
3	4.1	228	242	14

Although the initial DCP deficits are about the same, the final values are somewhat different because the outcome depends on the level and type of production of the animal. Nonetheless, in all cases a substantial improvement is made to the nitrogen economy of the animal.

A number of other subroutines are associated with the animal sub-model. These other subroutines are largely concerned with bookkeeping procedures. One subroutine, MOVEAV, computes the average daily weight change over the past 14 days. It also ensures that subroutine DROP, which handles calving, is called if any group of cows are 280 days pregnant. Two function sub-programs, NBUN and FACT allow random sampling from any binomial distribution. These sub-programs are used, for example, in the determination of the number of cows becoming pregnant after a call to subroutine BREED is made.

A call to subroutine BREED initiates simulated mating. The probability of pregnancy is determined in the function sub-program, PREGGO. Lamond (1970) postulated that the probability of conception was a function of liveweight, lactational status and plane of nutrition of the cow. However, no quantitative description of how these variables can be incorporated to provide an estimate of the probability of pregnancy was given. A relationship is used in the model that is intended to incorporate the concepts proposed by Lamond; the probability of pregnancy is calculated as a function of liveweight (WT, kg), liveweight changes over the past 14 days (WC, kg d^{-1}) and whether the animal is lactating (AL=1) or not (AL=0). The probability of pregnancy (P) is then defined by the following Fortran statments

```
P = - 0.9896 + 0.00697*WT - 0.5996E-5*WT*WT
             + 0.3586*WC - 0.1661*AL
P = AMIN1(0.96,AMAX1(0.02,P))
```

A sample of the predictions from this function is shown in Table 4.7.

Table 4.7 - Predictions from the function used in the model to estimate the probability of pregnancy

Lactating cows

14-day average liveweight change ($kg\ d^{-1}$)	Weight (kg) 200	400	600
-1.0	0.02	0.32	0.52
-0.5	0.02	0.50	0.70
0	0.02	0.50	0.70
0.5	0.18	0.86	0.96
1.0	0.36	0.96	0.96

Non-lactating cows

	Weight (kg) 200	400	600
-1.0	0.02	0.49	0.69
-0.5	0.02	0.66	0.87
0	0.17	0.84	0.96
0.5	0.35	0.96	0.96
1.0	0.52	0.96	0.96

An attempt was made to compare the predictions from the function PREGGO with several sets of data. It was not always possible to estimate the variables which are used to predict the probability of pregnancy in the model and often crude estimates, involving wide interpolations, had to be made. The data were obtained from the following sources: Wiltbank et al. (1961, 1962, 1964), Koger et al. (1962), Hight (1968a, 1968b), Sparke and Lamond (1968), Dunn et al. (1969) and F.H.W. Morley (unpub. data). The data were so widely scattered that they neither confirmed nor denied the proposed relationship. One difficulty is that the number of pregnant cows is a binomial variable and unless many animals are used to determine pregnancy rates, the errors of the estimates are very large. For example, if 34 cows out of 50 cows are pregnant, the approximate 95% confidence intervals (Snedecor and Cochran 1967) of the estimated pregnancy rate ($p=.68$) are

$$.55 < p < .81$$

The definition of a function which accurately predicts the probability of pregnancy remains to be achieved. It is unlikely that any general function will be developed in the near future since the variables which are likely to influence this probability (Lamond 1970) are rarely recorded concurrently with pregnancy rate.

Simulated calving is achieved through subroutine DROP. The birth weight of the calf (Y, kg) is determined as a function of cow weight (WT, kg).

$$Y = 16.4 + .032*WT$$

This regression was calculated from data presented in the following papers : Alexander et al. (1960), Wiltbank et al. (1962), Hight (1968a, 1968b), Bond and Wiltbank (1970) and A. Axelsen and F.H.W. Morley (unpub. data). No significant differences in between-author slopes were found. There was, however, a significant difference between the adjusted means ($P < .001$). The common slope ($b = 0.032$, $r^2 = 0.39$) was assumed and the relationship used in the model passes through the overall means of the above set of data (Figure 4.6).

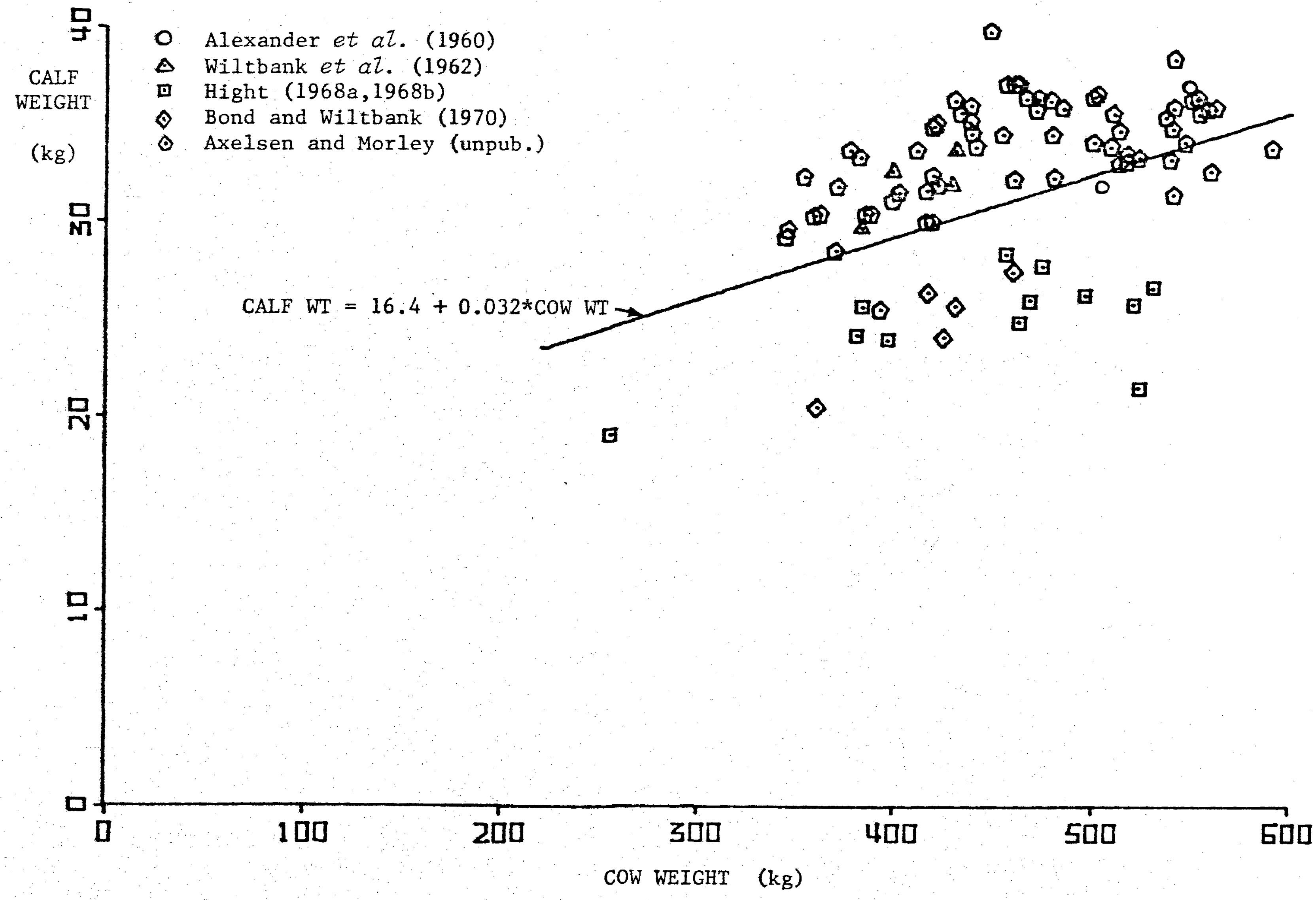

Figure 4.6 - The relationship between cow weight and calf birthweight reported by several authors. Unbroken line represents the relationship used in the model

After calving, the cow's liveweight is decreased by an amount equal to one and a half times the calf weight. Clearly, the cow's liveweight must decrease by the calf birth weight; the extra loss represents fluid and membrane losses which have been estimated to be approximately equal to half the calf weight (Hyppola and Hasunen 1970).

Weaning of suckling calves will occur if they have been suckling for longer than 200 days, if the daily milk yield falls below 1 kg or if the management decision to wean is made. The number of male and female calves is determined by sampling from a binomial distribution with a .5 probability of any calf being a male.

A record of the maximum weight reached by each class of animal within each paddock is maintained. Having reached a maximum weight (WTMAX) an animal's weight (WT) may decrease. If it decreases by more than 15% of WTMAX then the probability of death becomes positive. This curve can only be described as a "guesstimate". For both economic and humane reasons the relationship between liveweight loss and the probability of death will probabily never be measured. Yet, not to define some "mortality function" in the model resulted in "cattle" weighing only 1 kg. Thus, the modeller is forced to introduce a mortality function, virtually in the absence of data or theory. If weight loss exceeds 15% of WTMAX the probability of death is defined by the following Fortran coding

```
WTDIFF = WTMAX - WT
PERWTL = WTDIFF/WTMAX
PRBDTH = ((PERWTL-0.15)**3)*NOANIM*0.3
IF(PERWTL.LE.0.15)PRBDTH=0.0
```

where PERWTL is the fractional weight loss from WTMAX, PRBDTH is probability of death of an animal from a group and NOANIM is the number of animals in that class.

Consequently, if a group of 30 animals reach a weight of 350 kg and then lose weight to fall to a weight of 275 kg, the probability of death of an individual in that group is

0.0069. If such a group now increase their weight to 298 kg then the probability of death becomes zero. The mortality function is shown in Figure 4.7.

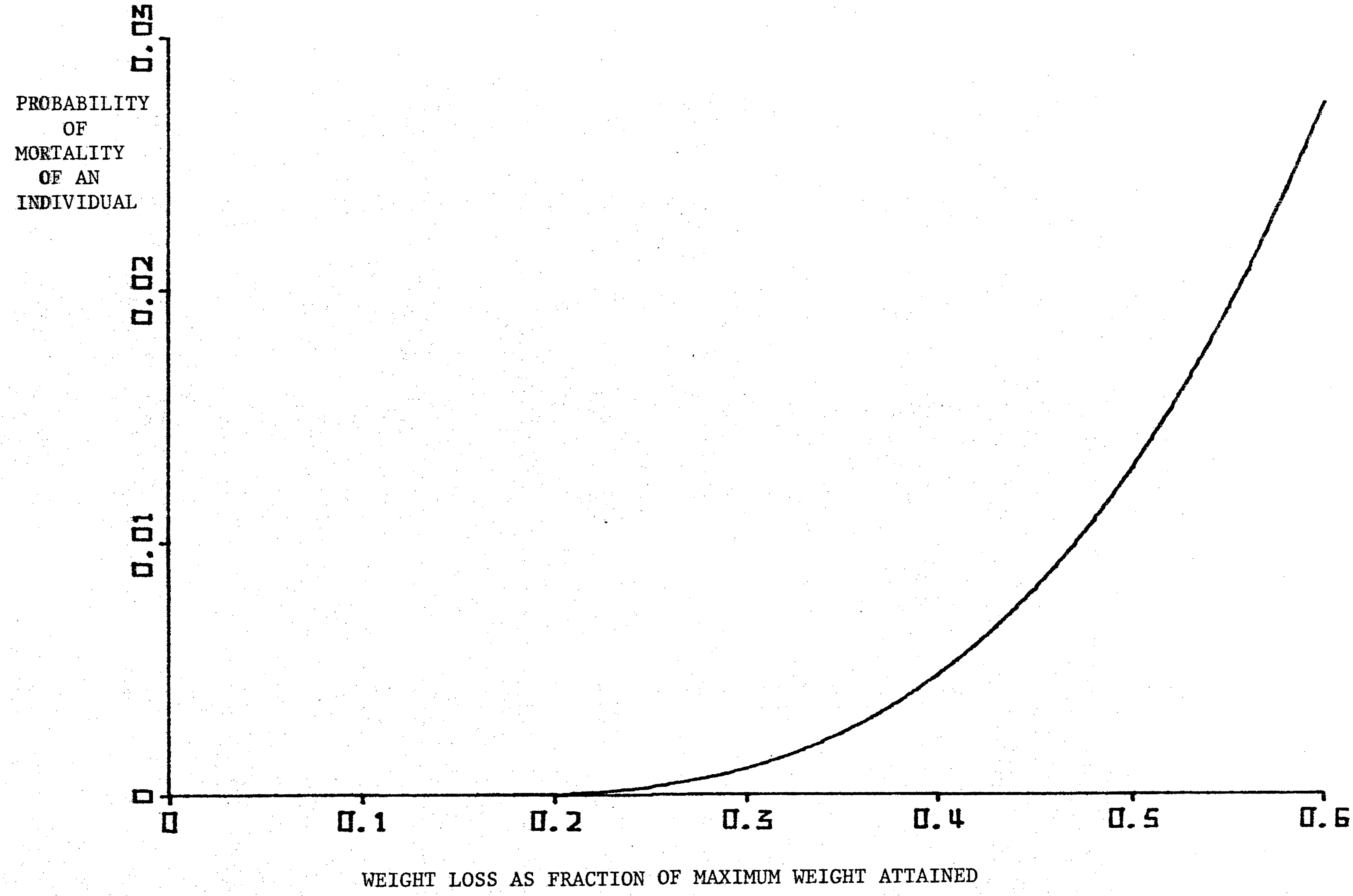

Figure 4.7 - Probability of death of an individual animal having lost different proportions of the maximum weight attained

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Chapter 5

VALIDATION AND TUNING

New techniques and new ideas are never short of critics. Simulation modelling of biological systems is no exception and has received its share of criticism, which has usually been verbal and occasionally written (Passioura 1973). Unlike most new techniques, simulation modelling is an ideal subject for the detractor because even time will not dispell some of the criticisms. For example, a criticism that could probably be levelled at most aggregative agricultural management models is that they have not been adequately validated. Whether the criticism is reasonable depends, of course, on how "adequate validation" is defined. In order to demonstrate the difficulty of comprehensive validation, a simple example follows.

Consider a simple model which has only 10 parameters. It is likely that some, if not all, of these parameters will vary continuosly but, because the point can be made if a restrictive constraint is put on the values assumed, let each parameter take say, three values. The number of different possible combinations of the parameters is $3^{10} = 59049$. In a model as simple as the hypothetical one being considered, the probability of comparing predicted and observed values over the parameter space is remote. Without such a comparison, a purist may argue that the model has not been validated; his position is unassailable.

However, a consequence of such a rigorous approach is that no extrapolation can be made using the model. If no other methods of extrapolation exist then presumably no attempt is made to examine the unexplored parameter space. Morley (1972) discussed a parallel problem: that of extrapolation from one grazing experiment at a particular site over a defined period of time to a new site where climatic conditions are different. Herculean problems of interpretation will exist in both cases, but, as Morley points out, to make no attempt at extrapolation could well be irresponsible.

Descriptions of modelling studies usually define a number of stages or phases in the total process. Three stages that are, at times, mentioned are model verification, tuning and validation. Wright (1971) distinguished between verification and validation, arguing that verification involved deciding whether a model was a true representation of reality whereas validation of a model depended on the purpose to which it was intended to put the model. By way of contrast, Jones and Brockington (1971) use the term verification to describe a process that Wright would undoubtedly have called validation. In fact, the distinction between these phases is, at best, fuzzy and they may be more conveniently considered as forming one stage.

Precise definitions are unlikely to be useful to the modeller during validation as he will probably be confronted with a model capable of spanning an almost infinite parameter space but with an obviously finite (and probably glaringly deficient) sample of data with which to "validate" it. The problem then becomes one of determining how the limited information can best be used. Obviously, this assessment will be a subjective one - a point discussed in some detail by Anderson (1974).

Following conventional scientific methods, one would probably argue that some data should be used to "tune" the model and then the tuned model's output compared with a further independent set of data. It is not a trivial point to note that this approach presumes that two independent sets of data exist. However, if a second set of data exists and the model output is compared with it there will undoubtedly be some discrepancies. If the model is adjusted to take account of these differences, then the second set of data is no longer independent of the model. On the other hand, to ignore the differences is to ignore a known deficiency in the model. Since at least one of the aims of a simulation study is to simulate a system with as few inaccuracies as possible, it rapidly becomes apparent that the niceties of independent comparisons must be subordinated to the objectives of the study. Consequently, all available information should ultimately be used to correct known deficiencies in the model.

Although all the available information should finally be used for what is effectively tuning of the model, some comparisons with independent sets of data, if they exist, are possible. All that is necessary is for the modeller to adopt a stepwise procedure, advancing through the sets of data one at a time. By adopting a stepwise approach, deficiencies in either the model or current theory may be highlighted by, for example, a spectacular lack of agreement with one of the sets of data. Attention will thus be focussed on that set and useful corrections may be made to the model, or hypotheses for experimental testing may become obvious. Real gains in information are made from an explanation of the discrepancies, not the similarities, between the model and data. Indeed, the situation is analagous to that of the interpretation of a field experiment. If, in the case of the field experiment, no differences between the observed and expected results occur then little information has been gained. On the other hand, if unexpected results occur, and can be explained, then a substantial increase in understanding of the system under study may result.

One reason for conducting a simulation study may be that the consequences of a set of hypotheses when incorporated into a dynamic model cannot be evaluated in ones mind. A corollary to this is that if the so-formed model does not agree with observed results it may not be obvious which of the hypotheses are in error. Nonetheless, a detailed comparison of the recorded data and the output from the model will be likely to indicate which assumptions are the major causes of any disparity. If large systems are being studied, a greater amount of time must be put into such comparisons and the subsequent alterations to the model are less likely to adequately correct the model's deficiencies.

Forrester (1971) pointed out that evolutionary pressures have not resulted in humans developing great powers in dynamic thinking, i.e. discerning the behaviour of a dynamic system from examination of the differential or difference equations which define that system. Also, a passing familiarity with multivariate analyis would be sufficient to convince most that we have little facility for thinking in several dimensions at once - few are the people who could predict the sign and order of magnitude of the least squares coefficients of, say, a four-variable regression equation from examination of the data. Yet it is the combination of these two skills that is required if a model is to be adjusted to conform with recorded data. If a system has been sampled on six occasions and five variables measured on each occasion, then an attempt to tune a model of that system to the recorded data involves the simultaneous comparison of six vectors each composed of five numbers. If one variable is consistently under- or over-predicted the tuning may be obvious. If, however, the differences are not systematic,and if the correction of one deficiency introduces another, the procedure becomes very time consuming.

In the process of tuning a trade-off must be established between the increased information obtained from copious model output and the very limited capacity of the human brain to interpret and understand such information. Consequently, models of simple systems may agree well with reality but there is a disproportionately lower likelihood of models of complex systems agreeing, particularly when operated over a wide range of conditions. Added to this is the problem, so widespread in biology, of random error in measured variables. The separation of signal from noise is necessary if a model is to simulate closely a system - the fact that this cannot be done, in general, with whole-farm studies can be regarded as imposing a confidence interval on any prediction.

A further problem that random error introduces is that a wide range of parameter settings may result in an approximately equally good fit of the model. The theory of minimizing an objective function (OF) may be appealing, but if a dozen different sets of parameter values give almost identical OFs the difficulty of choosing the "best" set confronts the modeller. No wonder Anderson (1974) regarded validation as essentially a subjective procedure.

The final aspect to be considered when validating a model is how to decide whether a run with altered parameters represents an improvement. If all variables are better predicted then the decision is straightforward. However, the decision as to whether a run which is 100 units out in the prediction of one variable and 40 units out in the prediction of a second variable is better than a run which is 80 and 60 units out respectively, is more difficult. Perhaps the simplest approach is to form an OF of these two variables and then minimize or maximize, whichever is appropriate, the OF.

In the following paragraphs the term validation is used in a generic sense to describe the total process of comparing the model with data and the consequent adjustments to the model. The alternative of introducing a further term to an already burdened literature was not invoked - in part, because a suitable term was not obvious.

Validation of the Soil Moisture Sub-model

The performance of the soil moisture sub-model (including the estimation of actual evapotranspiration) was compared with some field observations recorded at Canberra by G.T. McKinney (unpub. data). Parameter settings of the depths of the two soil layers considered, wilting point, field capacity and field saturation were estimated by McKinney based on his analyses and experience of the soil type in question. The maximum transpiration rates from the top and bottom soil horizons were 1.5 and .6 mm hr^{-1}. The goodness of fit, as judged by the mean square deviation, was compared when the parameter PENMAN (see Chapter 2) was set at .6, .7 or .8. Since the lowest mean square deviation was obtained when PENMAN=.7, this value was used in the model during summer.

A comparison of the model output for PENMAN=.7 and the observed results is presented in Figure 5.1. The soil

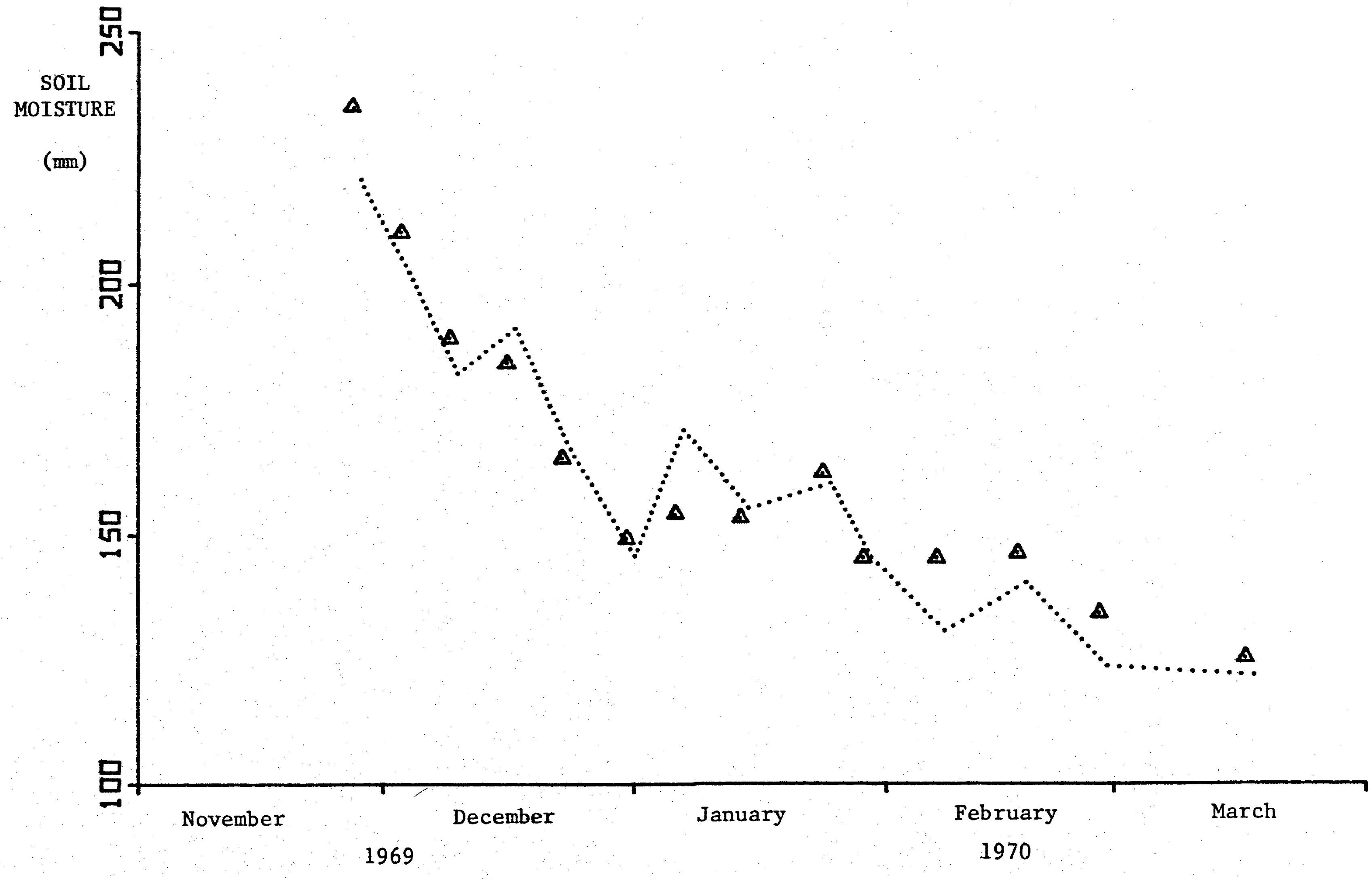


Figure 5.1 - Comparison of observed soil moisture (triangles) with predictions from the model

moisture sub-model provided a good description of soil moisture changes over the 120 days of the study. It should be remembered when assessing the goodness of fit that this test of the model is not as rigorous as it would be if several wetting and drying cycles had been simulated. With one cycle, the consequences of some systematic error, e.g. overestimation of moisture loss at low soil moisture, could be slight, but over several cycles the error might become more pronounced. Nonetheless, the agreement between model and data is quite good and gives some confidence in this section of the model.

Total Model Validation

The data available for validation of the total model were obtained from the study of Mears (1973). These data included information on the liveweight of animals, amount of green and dry pasture, and the botanical composition of the pasture over a period of 19 months. The variables were recorded at approximately 6-weekly intervals. The experiment from which the data were obtained was a replicated, incomplete factorial design - the factors being stocking rate and nitrogen fertilizer rate. Table 5.1 presents the treatment combinations used. Three animals, one heifer and two steers, grazed each paddock. These animals were replaced in late February by a further set of similar animals from the following calf drop.

Table 5.1 - Treatment combinations used in the experiment of Mears (1973)

Annual appl. of N (kg ha^{-1})	Stocking rate (animals ha^{-1}) 2.2	3.3	4.9	7.4	11.1	16.6
0	*	*	*			
134		*	*	*		
336			*	*	*	
672				*	*	*

The experimental site was an old dairy farm; one replicate being placed on what was formerly the "night-paddock" area. A difference in aspect was also associated with the replicates - with the exception of an occasional treatment, the replicates were on opposite sides of a gully. The result of these differences was that one "replicate" was of higher fertility than the other. The term "replicates" has been used in the following pages, although, because there were distinct differences between the replicates, it may be argued that "block" was a better term to use. There is little in the choice of either term.

It was obvious from ealier runs that the model behaved "sensibly" when stocking rate (SR) was altered or when nitrogen fertilizer (N) was applied. Hence, it seemed likely that if good agreement could be obtained between the model output and Mear's data for the treatments on the "corners" of the layout presented in Table 5.1 (i.e. low SR, low N; high SR, low N; low SR, high N; high SR, high N), then good agreement would be obtained over the SR-N surface. One of the "corner treatments" on the low fertility replicate (high SR, high N) was considered (Mears, pers. comm.) to be atypical. Hence, an adjacent treatment (medium SR, high N) was chosen in its place. One other treatment was also considered by Mears to be atypical, and it was not used in any of the validation studies. Thus, data from 22 treatments were available for the validation process. On several occasions in the following pages a shorthand notation has been used to define groups of the nitrogen treatments in Mears' experiment. For example, "N-336 treatments" refers to all the treatments receiving 336kg N $ha^{-1}yr^{-1}$.

A three-stage process of validation was adopted. First the model was tuned to the data obtained from the low fertility replicate. Second, when this had been achieved, the variables that defined soil fertility in the model were incremented and the output compared with data obtained from the high fertility replicate of the experiment. Thus, an assessment of how the model coped with different fertility conditions was obtained. Finally, the model output from the

22 treatments was compared with the experimental data and analyses of variance conducted on the differences between model and recorded data. This appeared to be one method of identifying systematic errors that exist in the model in either the stocking rate or nitrogen dimensions. It also provided a technique whereby all the information could be assessed at one time in a method concise enough to be absorbed and interpreted.

It was not possible to define quantitatively the fertility of the replicates and hence arbitrary values of FERTN and FERTP were assigned to the low fertility replicate. All that was known about the FERTN and FERTP values of the high fertility replicate was that these values would be greater than those on the other replicate. Thus, when comparing the data obtained from the high fertility replicate, a number of runs, each with different FERTN and FERTP values, were carried out. The fact that FERTN and FERTP could not be increased by a fixed amount, defined perhaps by soil nutrient measurements, serves to emphasize the qualitative nature of the term fertility, yet it is essential for simulation studies that such terms be quantified. This procedure was not seen as a rigorous validation but if good agreement between the model and data from the high fertility replicate were obtained then exploratory simulations with the model would be done with added confidence.

The OF formed for this validation procedure put different weightings on the seven variables being considered. The weightings were selected, bearing in mind the variances of the variables, so that discrepancies in pasture yields, liveweight, fraction of green pasture and botanical composition had an approximately equal effect on the OF. The differences between observed and simulated outputs were calculated, squared and multiplied by a weighting factor (W). The OF thus formed was defined by

$$OF = \sum_{i=1}^{7} W_i \text{ (Observed-Predicted)}^2$$

where the variables, weights and units of measurement are defined below

No.	Variable description	Units	Weighting
1	Pasture dry matter	kg ha^{-1}	0.00000015
2	Animal liveweight	kg	0.0002
3	Green pasture	fraction	30.
4-7	Botanical composition	fraction	8.

Thus, if the following output for one sampling occasion were obtained, then the OF would be calculated as shown in Table 5.2.

Table 5.2 - An example of the calculation of the objective function used in the model validation.

Variable	Observed value	Model pred.	Difference (D)	Weighting (W)	$W*D^2$
Pasture DM	6000	5000	1000	.00000015	.15
Animal LW	260	290	30	.0002	.18
% green	.38	.36	.02	30.	.012
Bot. Comp.					
species 1	.16	.11	.05	8.	.02
species 2	.38	.33	.05	8.	.02
species 3	.43	.51	.12	8.	.117
species 4	.03	.05	.02	8.	.003
			Objective Function = Total =		.502

The aim of the process of tuning was to minimize the OF summed over the 15 samplings for the four treatments being considered.

When comparing model output with recorded results the following procedure was used. Data from the first sampling period were used to define the initial conditions for each run. These data defined the initial liveweight, initial pasture on offer and the fraction of it that was green plus the botanical composition of the pasture. When the animals in the experiment were replaced, the liveweight of "animals" within the model was also altered. Thus, following the initial setting of liveweight and pasture variables, the only external changes to the state variables of the model occurred when the animals were replaced or when fertilizer was applied. Other than this, the model ran for 19 months being "driven" by the daily rainfall and mean temperature recorded over the period of the experiment. Fertilizer was "applied" in the model at the same time that it was applied in the experiment.

The first stage of the total model validation involved comparison of the "corner" treatments on the low fertility replicate. The model was tuned to these data by a process of trial and error. No fixed procedure was used, it depended on the magnitude of the differences between actual and predicted values and the time at which they occurred. Finally a stage was reached where altering a wide range of parameters did not improve the "fit" of the model. The fit obtained was well short of being perfect. However, it should be remembered that considerable between-plot variability existed. This variability was evidenced by a range in species ground cover prior to the commencement of the experiment (Mears 1973). To an extent this variablity was considered - the initial botanical composition of each treatment was read into and stored in the model before each run. This procedure did not take into account why (e.g. fertility differences) the plots had different botanical compositions. As there was no way to quantify between-plot differences, a constant base fertility was assumed in the model over each replicate (it differed between replicates); the actual fertility was affected by fertilizer application.

The agreement finally obtained between the model and the selected treatments on the low fertility replicate is shown in Figure 5.2. In general, there was quite good agreement. Where disagreement occurred it was not always clear that the

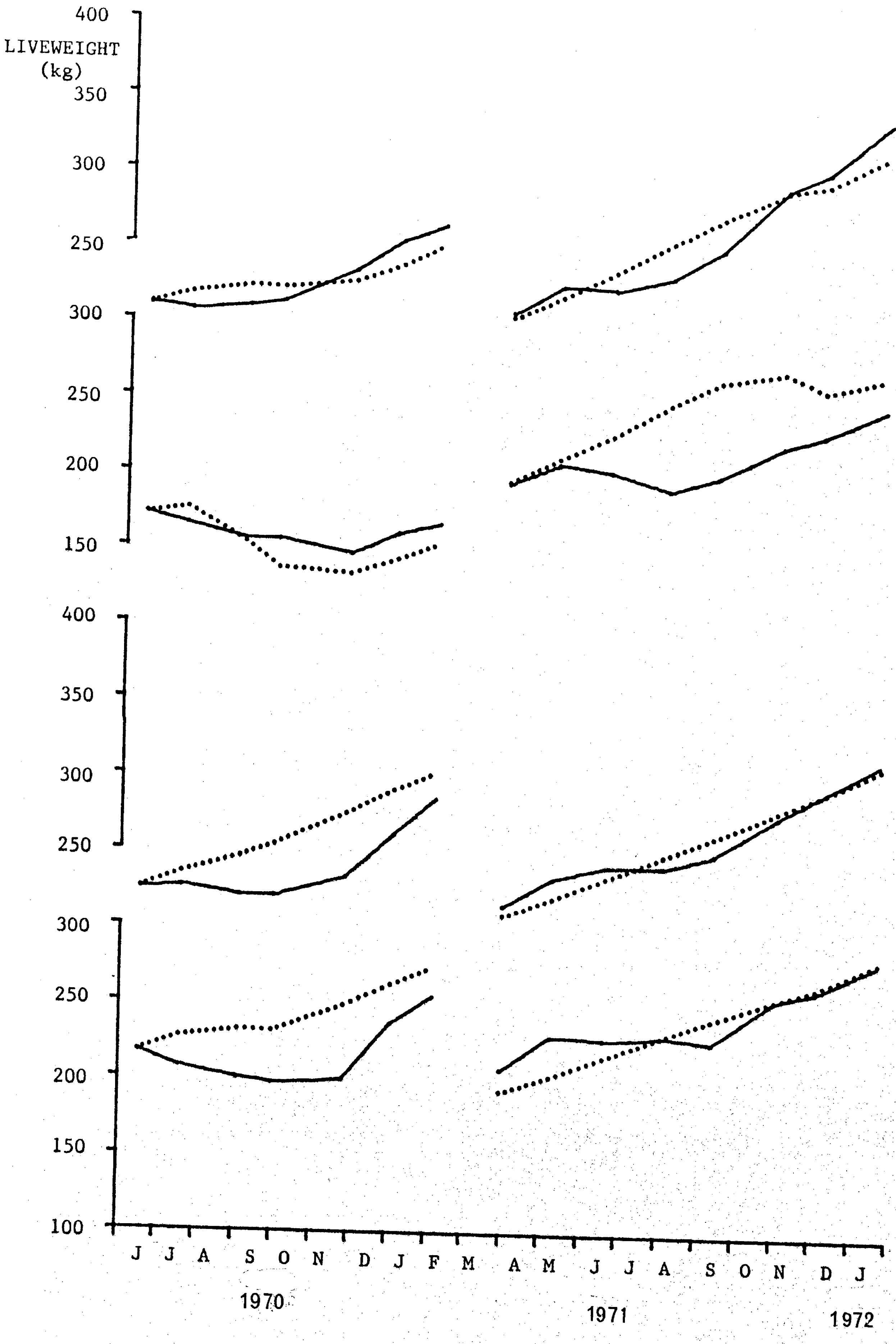
Figure 5.2 - A comparison of the model output and observed values on the low fertility replicate over a 19-month period. Model predictions are indicated by dotted lines.

Data were obtained from four treatments in the experiment of Mears (1973). In all graphs the order of appearance of the treatments is the same, namely

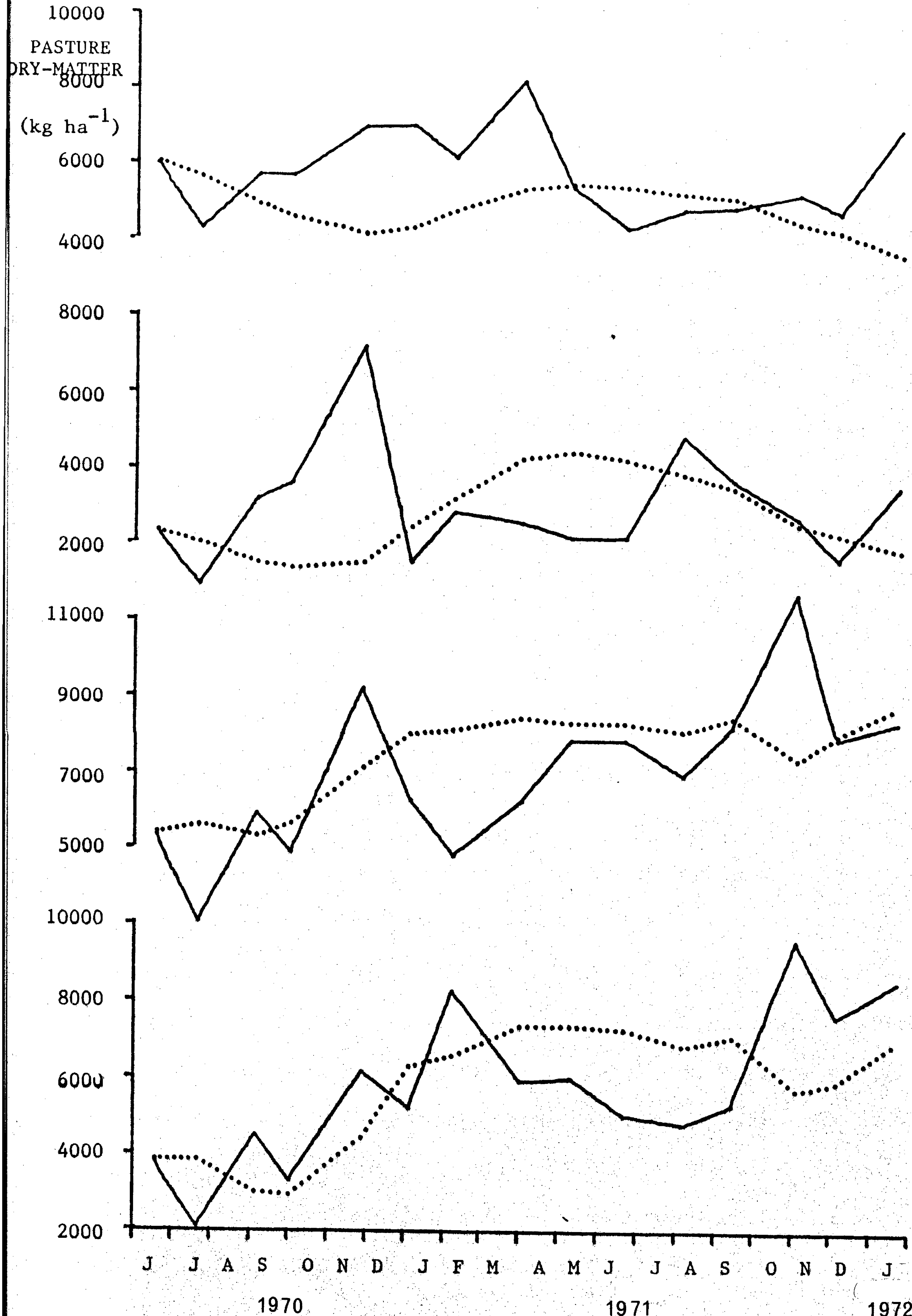
Stocking rate	N applied ($kg\ ha^{-1} yr^{-1}$)
Low	0
High	0
Low	672
Med	672

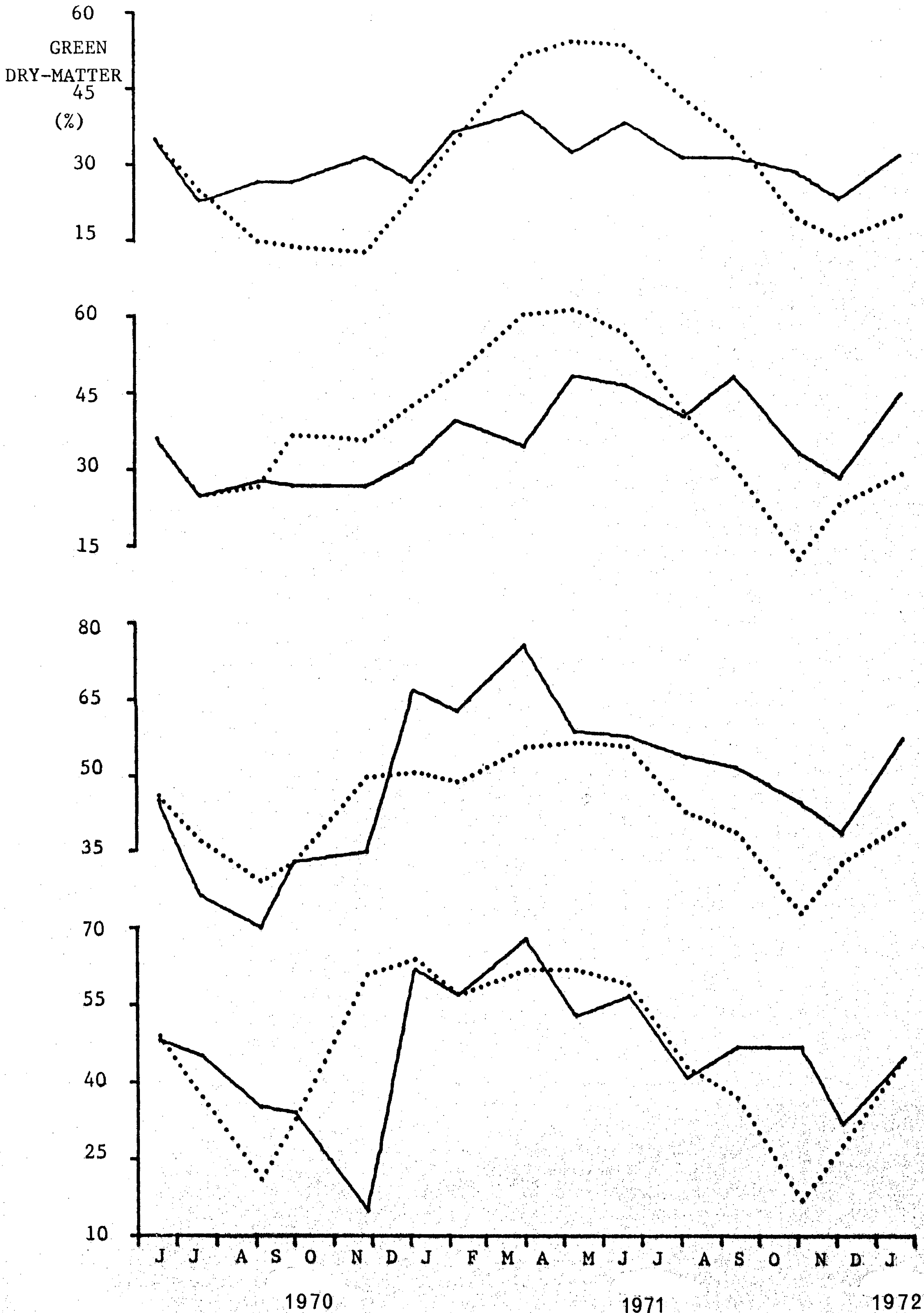
On each graph the ordinate scale is uniform, although starting values of the ordinate vary, depending on treatment.

Dominant grass in N-0 treatments was carpet grass, and in N-672 treatments was kikuyu.

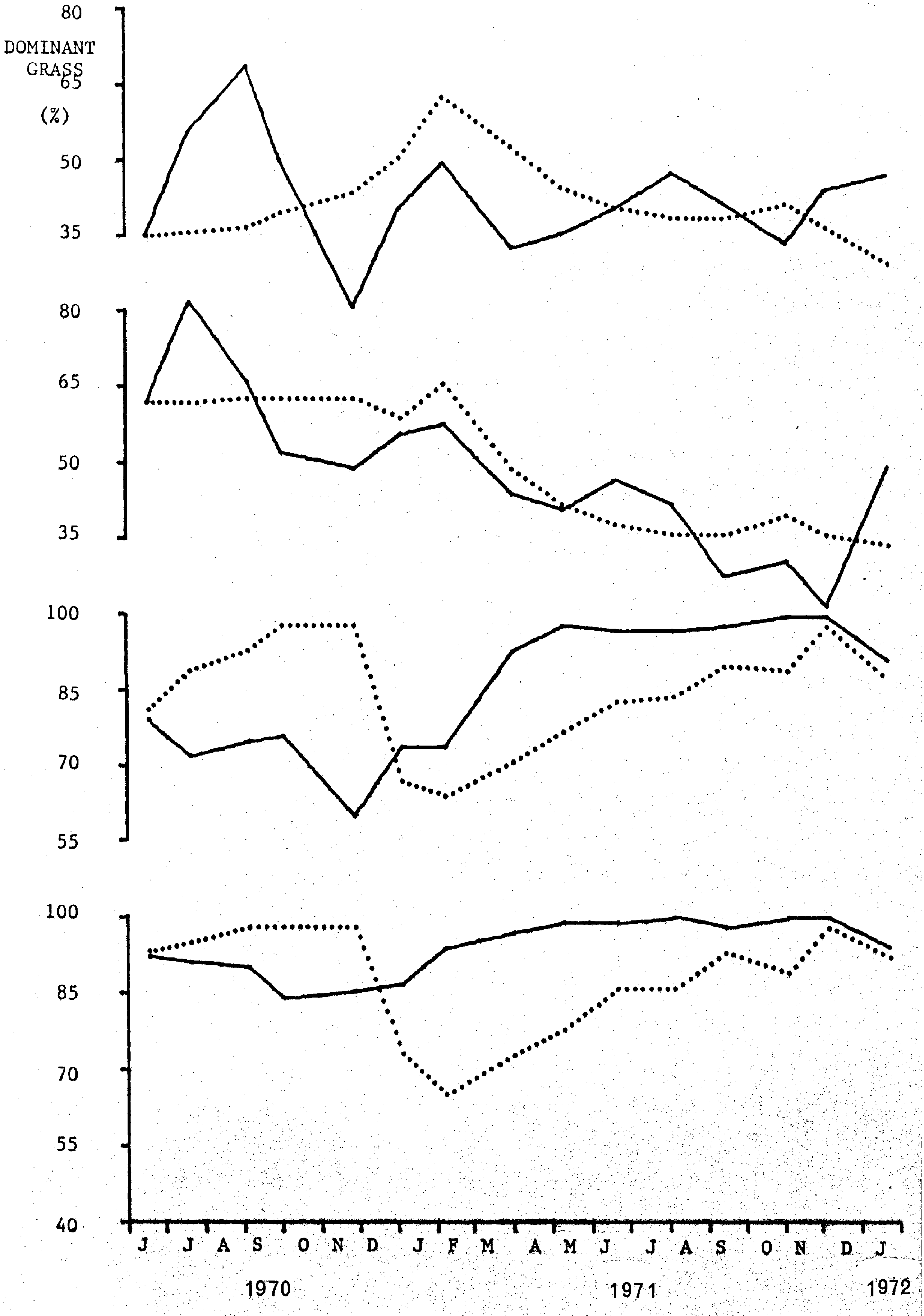


LIVEWEIGHT (kg)
400
350
300
250
300
250
200
150
400
350
300
250
300
250
200
150
100
J J A S O N D J F M A M J J A S O N D J
1970
1971
1972


10000
PASTURE
DRY-MATTER
8000
(kg ha^{-1})
6000
4000
8000
6000
4000
2000
11000
9000
7000
5000
10000
8000
6000
4000
2000
J J A S O N D J F M A M J J A S O N D J
1970
1971
1972



GREEN
DRY-MATTER
(%)
60
45
30
15
60
45
30
15
80
65
50
35
70
55
40
25
10
J J A S O N D J F M A M J J A S O N D J
1970
1971
1972


80
DOMINANT
GRASS
65
(%)
50
35
80
65
50
35
100
85
70
55
100
85
70
55
40
J J A S O N D J F M A M J J A S O N D J
1970
1971
1972

differences were due to deficiencies in the model. In particular, the large herbage yields recorded at the fifth sampling followed a fairly long dry spell. No rainfall run-off occurred in the model, and thus unless field saturation was reached this would cause an upward bias in modelled soil moisture levels, yet, low soil moistures (10-20 mm above wilting point) were predicted prior to the fifth sampling. No amount of parameter manipulation would have forced the model to cause a large amount of herbage to be on offer at that time. Indeed, even in qualitative terms I find it impossible to explain why so much was present. This may indicate a failure to appreciate the environmental control of pasture growth or it may be that some systematic error exists in the data of that date. Mears (pers. comm.) indicated that such an error may have been caused by a labour shortage on the Research Station at that time, resulting in different technicians sampling at different dates.

The next stage in the process of validation was to compare the output from the model, tuned to the low fertility replicate but with higher settings of the base fertility variables (FERTN and FERTP), with data obtained from the high fertility replicate. A number of runs were done with varying values of FERTN and FERTP. Good predictions of pasture on offer, percentage of green pasture and botanical composition could be obtained but the prediction of liveweight resulted in underestimates, particularly in the second year (Figure 5.3).

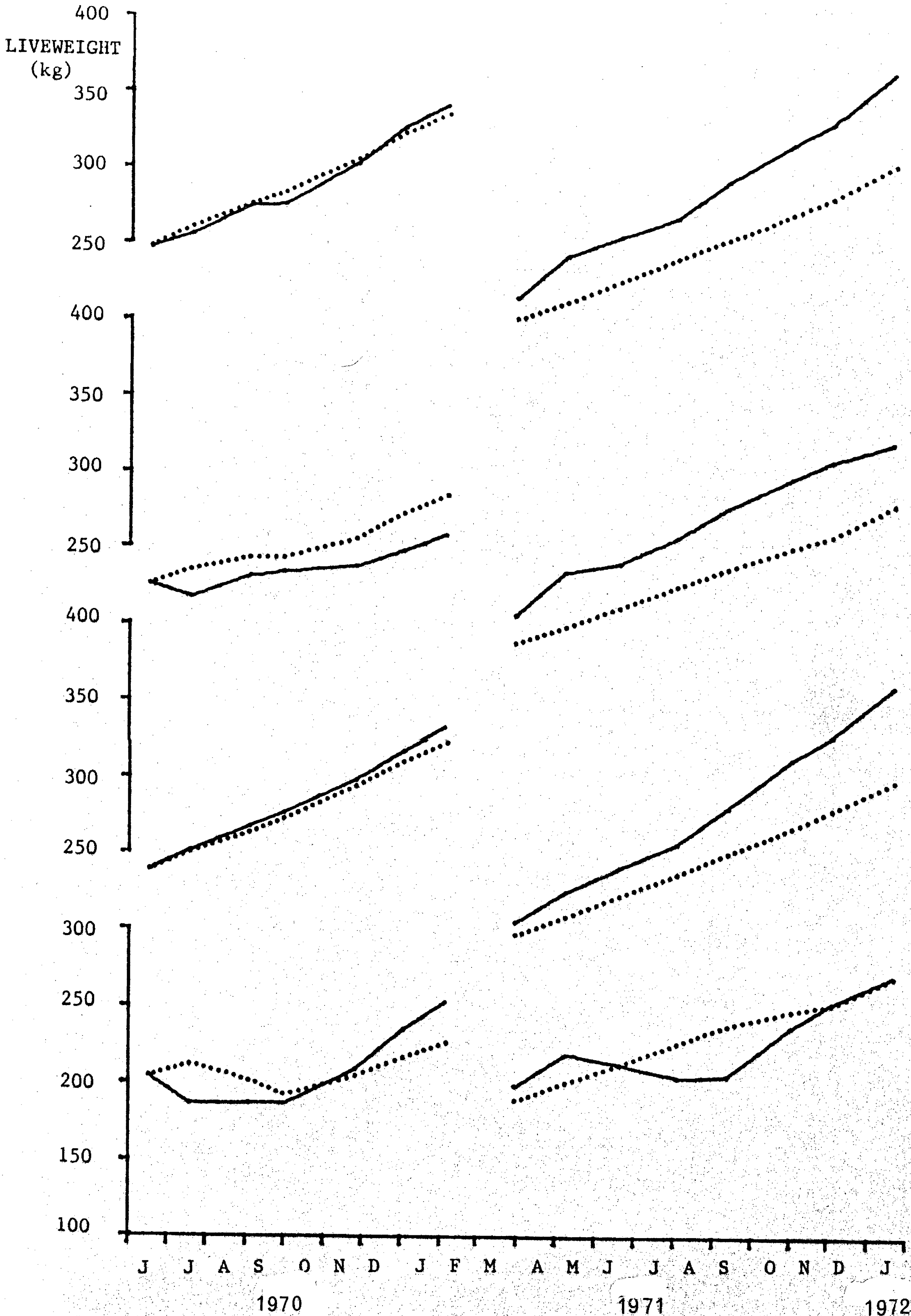
The poor prediction of liveweight on the high fertility replicate could not be explained. However, it was clear that increasing the amount of pasture consumed (e.g. by decreasing the FIBRE values on the high fertility replicate or increasing the DIGEST values on the high fertility replicate) would yield predictions as good as were obtained on the other replicate. To do this could be interpreted as "fudging" to correct inadequacies in the model although one could invoke an effect such as that found by Ozanne and Howes (1971) to rationalize the use of the fudge. Ozanne and Howes found that sheep consumed more pasture which had received an

Figure 5.3 - A comparison of the model output and observed values on the high fertility replicate, following validation of the model against data from the low fertility replicate. Model predictions are indicated by dotted lines.

Data were obtained from four treatments in the experiment of Mears (1973). Order of appearance is,

Stocking rate	N applied ($kg\ ha^{-1}\ yr^{-1}$)
Low	0
High	0
Low	672
High	672

The ordinate scale is uniform for the graph, although starting values of the ordinate vary, depending on treatment.



LIVEWEIGHT
(kg)
400
350
300
250
400
350
300
250
400
350
300
250
300
250
200
150
100
J J A S O N D J F M A M J J A S O N D J
1970
1971
1972

application of phosphorus fertilizer, although the low fertilizer treatments contained what appeared to be adequate concentrations of phosphorus.

A five percent decrease in the FIBRE value of feed selected by animals on the high fertility replicate resulted in good agreement being obtained between the model and data. It must be stressed that this was not a satisfying method of tuning as application of the model to other sites would require prior knowledge of how much the FIBRE value should be increased or decreased.

The final stage of validation was now entered in which the model predictions and data from the 22 "typical" treatments were compared. A number of features of the model and data soon became obvious. Given the rainfall and temperature patterns that existed, no amount of parameter manipulation could produce good agreement between the model and the data over the full 19-month period. The data indicated an increase in pasture dry matter during the first 100 days of the comparison although only a small amount of rain (66.9 mm) fell in that interval and the previous two months had been quite dry.

Between-plot variability has already been mentioned. The extent of this variability in liveweight gain was alarming and is demonstrated in the following table. Entries in Table 5.3 were obtained by calculating the liveweight gain in each plot from the date of the first observation till animals were removed, in both years. The differences between plots with the same stocking rate-nitrogen combinations but in different replicates were then calculated. Thus, the entry in the i-th row and j-th column (A_{ij}) was calculated as:

$$A_{ij} = 1R_{ij} - 2R_{ij}$$

where $1R_{ij}$ = liveweight gain from animals on the i-th stocking rate, j-th nitrogen level, replicate 1

$2R_{ij}$ = as for $1R_{ij}$, except replicate 2

Table 5.3 - Between-plot variability in liveweight gain (kg). See text for details of table entries

	Stocking rate	Nitrogen rate (kg $ha^{-1} yr^{-1}$) 0	134	336	672
Year 1	Low	50	-30	11	22
	Med	2	11	60	29
	High	44	40	-10	62
Year 2	Low	42	14	-4	31
	Med	-27	54	48	30
	High	68	105	17	108

Some agreement exists between the two years (r^2= .458), however, the disagreement that exists does not follow any systematic pattern. The differences between respective entries in different years range from -29 (medium stocking rate, N-0) to 65 (high stocking rate, N-134) - a range of 94 kg. It would be an extraordinary model that could track such variability.

A second feature of the data, when viewed "in total", was that liveweight did not respond as would be predicted from observation of the pasture variables. Regressions were calculated between liveweight change (dependent variable, Y) and the following independent variables:

X_1 Total pasture dry matter
X_2 Fraction of green in the pasture.
X_3 Green pasture dry matter
X_4 Dry pasture dry matter

Data were obtained from all treatments within a period (generally about six weeks duration). The independent variables were calculated as the mean value of the variables at the beginning and end of each period and the following sets of independent variables were used

(X_1,X_2), (X_3,X_4) and (X_2,X_3,X_4);

thirteen regressions were calculated for each set of variables. A list follows of the range of adjusted R^2 (Fisher 1924) values and the number of significant ($P < 0.05$) regressions.

Independent variables	Adjusted R^2 minimum	mean	maximum	Number of significant regressions
X_1, X_2	-0.06	0.25	0.53	9
X_3, X_4	-0.08	0.25	0.55	8
X_2, X_3, X_4	-0.11	0.25	0.53	8

Clearly, these variables either singly or in combination were explaining only a small proportion of the total variation. The magnitude of the coefficients fluctuated, in some cases varying between positive and negative. There was some evidence of seasonal variation in the value of the coefficients (2 of the 10 coefficients calculated followed significant ($P < 0.05$) seasonal trends).

It would be unlikely that the X_i could have explained all variation in Y but it was expected that they would account for the majority of it. There are several reasons why perfect correlation could not be obtained between the X_i and Y, they include (i) random error, (ii) biases in the variables and (iii) incorrect specification of the regression model - an important variable may have been left out of the regressions which, if included, would have yielded high correlations. Certainly, random error existed but it seems an improbable explanation for correlations as low as were obtained. Biases caused by the use of different technicians and hence techniques in the pasture sampling and cattle weighing, or biases caused by alterations in gut-fill of the cattle may be implicated. In fact, in the later samplings the same people sampled the plots, yet the later observations did not provide regressions with higher R^2 values. Also, as large changes in gut-fill are usually associated with dramatic dietary changes (e.g. grass to clover) and as pastures did not, in general, undergo violent fluctuations (Figure 5.2) in the measured variables, it would seem unlikely that gut-fill would have altered enough to account for the high residual variation.

The most likely reason that so little of the variation was accounted for appears to be inadequate specification of the regression models. Possibly they should have included factors such as degree of parasite infestation, the effect of fertilizer on pasture quality, systemic disease and an assessment of the productive ability of each animal. However, as no measurements were made of these variables, their effect can only be regarded as "noise". The question of whether there is true random variability in Nature, or whether it is a failure on man's part to see the causes of apparently random behaviour is, no doubt, important to philosophers of Science. The question was, however, rather irrelevant to the validation of this model as no matter what the cause, the result is unexplained variation. Consequently, a limit is immediately placed on the accuracy with which a simulation model could predict liveweight change even if it is assumed that the model faithfully reproduces the pasture parameters.

It was now evident that the model would not fit the data very well no matter what alterations were made. However, it was decided that if a version of the model predicted stocking rate, nitrogen and replicate means reasonably well, although agreement with individual treatments might not be good, then that version would be accepted as the validated model.

During the final phase of validation many runs of the model were made involving parameter and, at times, structural changes. One structural change was to alter the feed selection routine. To determine the fraction of the total diet (COMP) obtained from one of the plant pools, given that COMPON kg of that pool existed, an equation of the following form was initially used

COMP = 1.0-EXP(-C*COMPON)

where C is a postive constant. The results of one run of the model suggested that an alternative form of this relation might be more suitable. Hence, a linear function with slope 0.001 was used (Figure 4.2). This substitution resulted in a better fit and obviated the need to consider that the high fertility replicate provided intrinsically better feed.

The recorded increase in pasture yield in the first three months of the experiment remained a perplexing problem. No variable concerned, or information available, could account for this increase. Consequently, opposite trends existed between the model and the experiment in the early stages - a pasture increase and liveweight gain being recorded whereas the model predicted a pasture decrease and liveweight loss. If the initial estimate of pasture yield had been an underestimate, then many of the discrepancies would have been either resolved or reduced. With this in mind, the arbitrary step of increasing the pasture dry matter estimate at the first sampling by 50% was taken - implictly assuming that a systematic error (such as a new technician) existed at that sampling. This change resulted in much better agreement being obtained between data and model.

The differences between the observed and predicted results were subjected to an analysis of variance in order to test for systematic differences between predicted and recorded results. The data were analyzed as if they came from a replicated orthogonal factorial design with three stocking rates (SR: low, medium and high) and four nitrogen rates (N: 0,134,336 and 672 kg ha^{-1}). The two treatments not used in the validation were considered as missing plots.

There are good reasons for arguing that this is not the most appropriate form of analysis. Mears (1973) analyzed the effect of SR within N levels, thus avoiding the classification of both 2.2 weaners ha^{-1} (N-0) and 7.4 weaners ha^{-1} (N-672) as "low" stocking rates. The major advantage obtained in regarding the design as an orthogonal 3x4 factorial was in ease of analysis and savings of computer time. A computer package existed to perform such an analysis whereas an analysis of the form used by Mears was not readily available.

Data from each of the 15 measurement periods and from the following seven variables were analyzed: liveweight, total pasture dry matter, percent green in pasture and the fractions of carpet grass, paspalum, kikuyu and white clover in the pasture. The analysis tested for significance of the effects of SR, N and SRxN interaction. The 15 samplings x 7 variables x 3 tests of significance resulted in 315 tests of significance being made. At the 5% level of significance, even with no treatment or interaction effects, one could expect about 16 "significant" effects. The analysis revealed that 33 "significant" effects existed. This represented a substantial improvement on the number of significant effects (77) found when comparing the differences between the data and model when tuned to the "corner" treatments of both replicates. This is interpreted as indicating a considerable improvement in the "reality" of the model after the final stage of validation.

Because of the high between- and within-plot variability in the experimental data, individual plots were not compared. Rather, attention was directed towards the SR and N means. Good agreement between prediction and observation was obtained with the botanical composition data but other variables were not as well predicted. In part, the poorer agreement resulted because in the experiment the N-336 treatments appeared to be particularly favoured - mean liveweight gains from the N treatments for the first two years of the experiment were

N treatment ($kg\ ha^{-1} yr^{-1}$)	0	134	336	672
Liveweight gain ($kg\ hd^{-1} yr^{-1}$)	127	114	140	107

The mean differences between the experimental data and the model results for the variables are given in Table 5.4. Several features of the entries in this table stand out. Liveweight at high stocking rates was over-predicted; the pasture dry matter was, on average, under-predicted; as stocking rate increased the fraction of green in the pasture and the fraction of carpet grass in the sward was over-predicted.

Table 5.4 - The mean* differences between the experimental data and the model. Negative values indicate that the model predicts a value too large.

Variable	Stocking rate			Nitrogen rate			
	Low	Med	High	0	134	336	672
Liveweight(kg)	6	-1	-8	-11	-3	18	-9
Pasture DM(kg ha^{-1})	821	860	343	-374	810	1885	139
Fraction green	0	-.01	-.04	-.02	-.04	.02	-.03
Fraction of							
carpet grass	0	-.02	-.04	0	-.02	-.05	-.01
paspalum	0	-.01	.02	.01	.03	-.03	0
kikuyu	.01	.01	.04	-.03	0	.10	0
white clover	0	.01	-.02	.03	-.01	-.02	0

*mean of the 15 sampling periods.

As stocking rate increased, there was a tendency for the model output to over-predict liveweight; this was largely caused by disagreement between predictions and data over a period of two samplings. During this time the model predicted a liveweight gain whereas the data indicated that no change in liveweight occurred. The model also over-predicted the amount of pasture during this time - it was probably this that caused the discrepancy in liveweight. All runs of the model exhibited this same tendency and it was not clear how, if at all, the model could be constrained to reduce such disparities.

The model did not predict the correct amount of pasture, however, it would have been fairly simple to adjust the model to give much better average predictions (e.g. by decreasing pasture senescence and decay rates). This was not done as it was under-prediction in the last few samplings that was the major cause of the discrepancies in Table 5.4 and it was not clear why such differences should exist. A big increase in dry matter was recorded yet, in the model, the soil moisture level was frequently so low as to cause considerable moisture stress during this time. It was judged to be more suitable to retain reasonable agreement for about 11 samplings and poor agreement for a few than to obtain a worse fit in 11 merely to get a better fit for the last few samplings.

The over-prediction of the amount of green material in the pasture at high stocking rates, especially when total availability was high, plagued the final phase of validation. It is possible that the disagreement occurred because the dietary selection routine was in error and over-predicted the amount of dead material consumed at low availabilities. If less dead material had been consumed, then not only would this leave a larger dead pool but it would also reduce the size of the green pools and hence, reduce the rate of pasture regrowth. Alternatively, the senescence rate may be influenced by the size of the green dry-matter pools.

These difficulties are examples of some of the common problems that exist in validations of complex systems. If, in this case, one opted to alter the pasture decay rates when the section in error was the dietary selection routine, then the chance of agreement between data and other sections of the model would be reduced. Yet, to not alter one of the sections will cause a known and avoidable disagreement between model and data. Dilemmas of this sort consistently face the modeller and decisions must be made with virtually no method of determining, at the time, whether the correct decision was made.

The final major point of systematic disagreement was the over-prediction of the fraction of carpet grass as stocking rate increased. It is not clear why this occurred, nor, if it is a real effect, how it could be remedied. It could well be the result of an interaction between the fraction of carpet grass and stocking rate.

Poor prediction of liveweight, amount of pasture and fraction of kikuyu was a feature of the simulation of N-336 treatments. It has already been mentioned that, by chance, the N-336 treatments seemed to have been especially favourably sited. It is therefore somewhat comforting to find that the model under-predicted the liveweight and pasture dry matter for these treatments. The poor prediction of the amount of kikuyu can be explained if it is accepted that the N-336 treatments received better than average sites, since a high percentage of kikuyu is a feature of high fertility sites.

The final version of the model is presented in Appendix C. Not all subroutines or functions are listed because many fill only a bookkeeping capacity, or the essence of them has already been described, or reference to the relevant parts has been made previously. An example of this is the function which generates standard normal deviates using the technique of Box and Muller (1958).

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Chapter 6

SENSITIVITY TESTS

Sensitivity testing is one of the traditional stages of modelling. A sensitivity test typically involves varying a parameter of the model through a range of values and observing the consequent model output. More complex versions of sensitivity testing may include alteration of functions (i.e. a set of parameters) or, in a stochastic model, may include the alteration of one or more of the probability density functions. Finally, the progression in complexity will lead to an event, which is more likely to be termed "system testing", in which the changes between the "standard model" and the new one are quantitatively so large that they can almost be considered as qualitative differences. An example of such a progression follows. Consider a model of a farm. An initial sensitivity test may examine the outcome of different amounts of pasture available at the commencement of the simulation year. If the effects are considerable this may lead to an examination and sensitivity testing of, perhaps, the fertilizer response routine. It is then only a short step to examine a system of deferred grazing (to ensure a feed build-up) with the implied testing of various rotational grazing/fertilizer strategies.

There are several reasons for conducting a sensitivity test. It may be conducted in order to test whether a doubtful assumption, or a simplifying assumption, has a large influence on the output. Alternatively, identifing the parameters which are particularly "sensitive" may indicate where accuracy is highly necessary. This, in turn, may aid in deciding research priorities.

In a sense, the conduct of single parameter sensitivity tests on a complex model is an implicit contradiction of the reason for constructing the model. The difference in model outputs from two different values of one parameter may not be the same if interactions are present in the system and other parameters are varied. Since a major justification for model construction is often stated to be to allow for interactions (and feedbacks are essentially interactions), a restricted sensitivity test may be of limited value.

The sensitivity of a parameter may be directly linked to that of another parameter. In the description of the climate generator, it was pointed out that an increase in evapotranspiration rates could be compensated for by an increase in the depth of the soil layers, and hence an increase in the size of the soil moisture pool. In a similar way, animal intake and maintenance requirements may readily be varied inversely to give the same output, provided availability of pasture is not limiting.

Three sensitivity tests involving only single parameter or minor changes and one system test were undertaken. The first sensitivity test compared the consequences of having under- or over-estimated the maximum pasture growth rates attainable. In the second test the pasture growth rate/availability relationship was altered and in the final test the effect of including a rainfall run-off function was examined. The system test is discussed separately. All tests were conducted over a series of three years and at three stocking rates (2.5, 4.5 and 6.5 animals ha^{-1}). The initial conditions were reset at the beginning of each year and were :

Commencement of "year" was day 60 (i.e. 1st March),
No rain fell on the previous day,
Animal weight was 200 kg,
Soil moisture was 225 mm (88% of field capacity),
Pasture availability = 4000 kg $ha^{-1}$of which 50% was green,
Botanical composition was 30% of each grass species and 10% clover.

In the following sensitivity tests, the same three years' climatological data were generated. The monthly and yearly rainfall totals for the three years are shown in Table 6.1.

Table 6.1 - The three years simulated rainfall used in all sensitivity tests. Rainfall amounts are expressed in mm.

Month	Year 1	Year 2	Year 3
March	214	650	286
April	4	379	185
May	143	198	161
June	46	22	49
July	59	69	258
August	22	185	130
September	129	17	133
October	13	51	5
November	130	87	101
December	151	99	131
January	184	217	211
February	77	346	161
Total	1172	2319	1811

Sensitivity to Maximum Pasture Growth Rate

The effects of alterations of maximum pasture growth rate on model output can be assessed from the results shown in Table 6.2. Increasing growth rate caused an increase in the amount of pasture on offer and this in turn caused greater liveweight gains. As stocking rate was increased the consequences of low pasture growth became more severe.

One feature that is not adequately brought out from Table 6.2 is the between-year variation and the importance of rainfall distribution, as much as total rainfall, in the determination of productivity. The second of the three years yielded the lowest animal production from all treatments, despite the fact that the total rainfall for the 12 months was double that in the first year (Table 6.1). Liveweight gain in the third year was 10-15 kg greater than that in the first year; the first year was 25-35 kg better than the second. Hence, from this sample of three years a between-year range of about 45 kg liveweight gain per head existed. At high stocking rates and low pasture growth rates this difference would have been even greater had the mortality function (see Chapter 4) not been included in the model. Of the 100 animals that commenced year 2 at the high stocking rate and low pasture growth rate, only 38 "survived" whereas 87 survived in year 3.

Table 6.2 - The sensitivity of the model to decreasing and increasing maximum pasture growth by 20%. Values presented are the means from a run of three years. Growth rate is in relative units and stocking rate in animals ha^{-1}

Growth rate	Stocking rate	Liveweight gain (kg) per hd^{-1}	per ha^{-1}	Pasture[a] kg ha^{-1}
80	2.5	11	28	3694
80	4.5[b]	-24	-108	2795
80	6.5[b]	-89	-579	2523
100	2.5	48	119	4456
100	4.5	22	99	3466
100	6.5[b]	-27	-173	2776
120	2.5	76	191	5116
120	4.5	46	207	4107
120	6.5	27	178	3199

[a] pasture at end of year
[b] "deaths" occurred in these treatments

These results show the expected trend. However, it would be difficult to guess the approximate quantitative effect of increasing the maximum pasture growth rate without a model. Although the lower maximum growth rate caused the pasture to be grazed lower (Table 6.2), the lower availability need not have resulted in very different pasture growth rates. For example, referring to Figure 6.1, if the animals grazing the pasture with the lower maximum growth rate were grazing at availability A then the growth rate of this pasture would be the same as that of the pasture defined

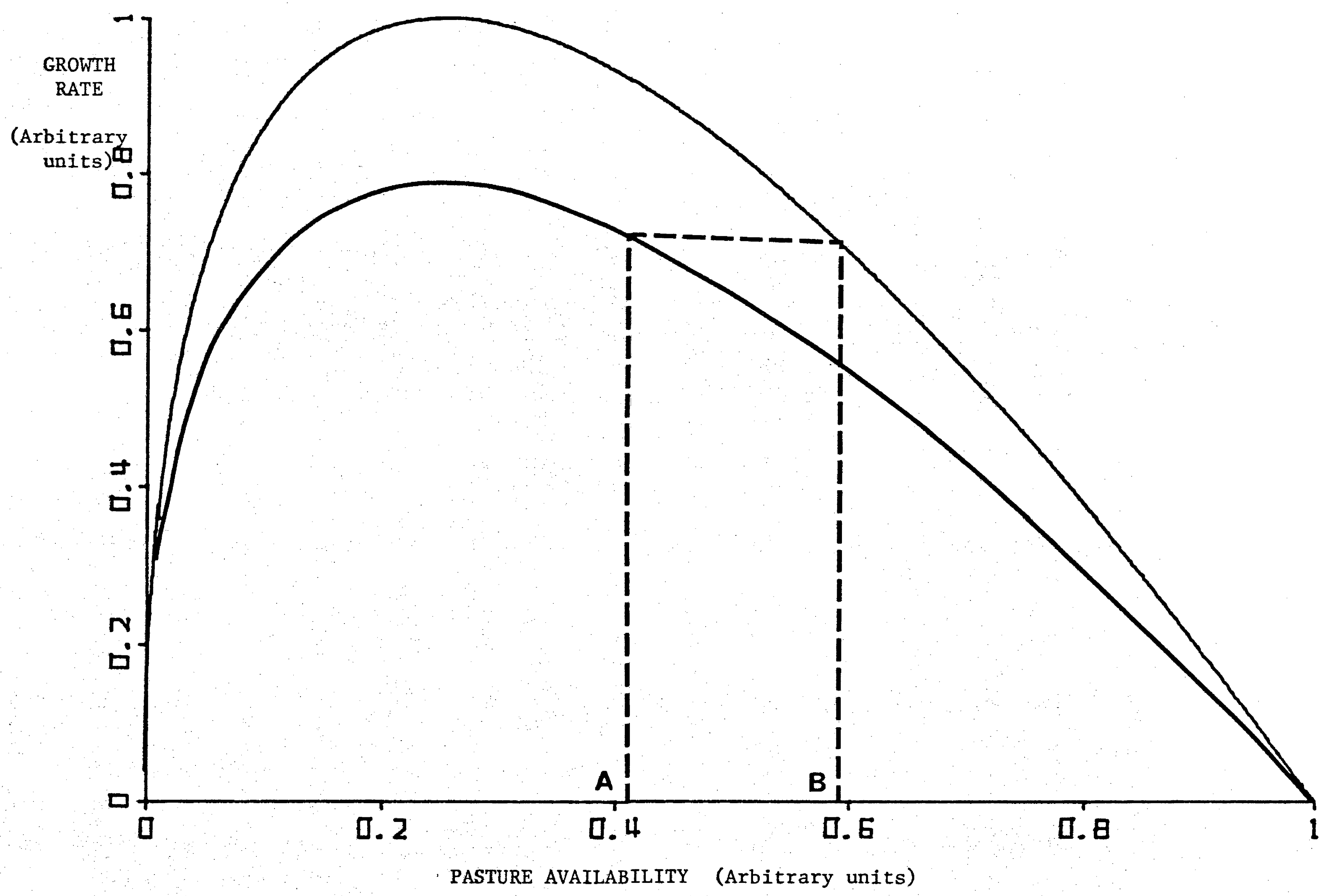

Figure 6.1 - The relationship between growth rate and availability; maximum growth rate of the lower curve is 80% of that of the upper curve. Growth rate of lower curve at availability A equals that of the upper curve at availability B.

in the second curve at point B. An example follows of how the dynamic interrelationships can have surprising effects on the model output.

Mean observed growth rate of carpet grass ($kg\ ha^{-1} d^{-1}$)

Maximum growth rate	Stocking rate (animals ha^{-1}) 2.5	4.5	6.5
80	19	21	20
100	24	24	27
120	28	33	32

At the maximum growth rate setting of 100, the highest average daily growth rate of carpet grass was found at the high stocking rate, whilst in the other treatments the medium stocking rate produced the greatest average daily growth rates. This effect is the result of the many feedbacks and interactions within the model and was not predicted beforehand.

The results of this sensitivity test serves to underline the necessity of defining pasture growth rates with a fair degree of accuracy if the model is to be realistic. This comment is also relevant to factors which directly impinge on the calculation of pasture growth rates. For example, the determination of whether pasture growth rate is proportional to evaporation ratio, other things being equal, is a study that could well prove productive.

Sensitivity to the Growth Rate/Availability Function

In Chapter 3, reasons were given for choosing the Richards function to define the relationship between pasture growth rate and availability. In the model, values of 0.5 for the grasses and 0.8 for clover were assigned to variable RICHUD. A value of 2 for this parameter results in the definition of the logistic growth curve. The most appropriate setting for parameter RICHUD has not been defined experimentally, yet it seems likely that alterations to its value could have a profound effect on the output from a model. Hence, the following sensitivity test examined the effect of using different values for RICHUD.

Three different sets of values were compared. These sets were defined by the following vectors in which the first element is the value for grasses and the second the value for clover: (0.5, 0.8), (0.999, 1.3) and (2.0, 2.0). The value 0.999 was used to approximate 1.0; the value 1.0 could not be used because the differential equation defining growth rate (Chapter 3) involves a division by (1.0 - RICHUD). A plot of the relationship between growth rate and availability for values of 0.5, 0.999 and 2.0 is shown in Figure 6.2. As the parameter increases, the maximum of the curve moves to the right; consequently, a lower growth rate occurs at low availabilities.

The results of this sensitivity test are presented in Table 6.3. The effects of altering the value of RICHUD from that used in the model to the value which defines a logistic growth curve were more pronounced than expected. The effect was manifested particularly at the high stocking rate because, as pasture availability became low, if a logistic form of growth was assumed the rate of regrowth was initially much slower (Figure 6.3). Data for pasture availability are not presented in Table 6.3, however, the nature of the availability differences can be deduced from observation of the liveweight gain per head figures.

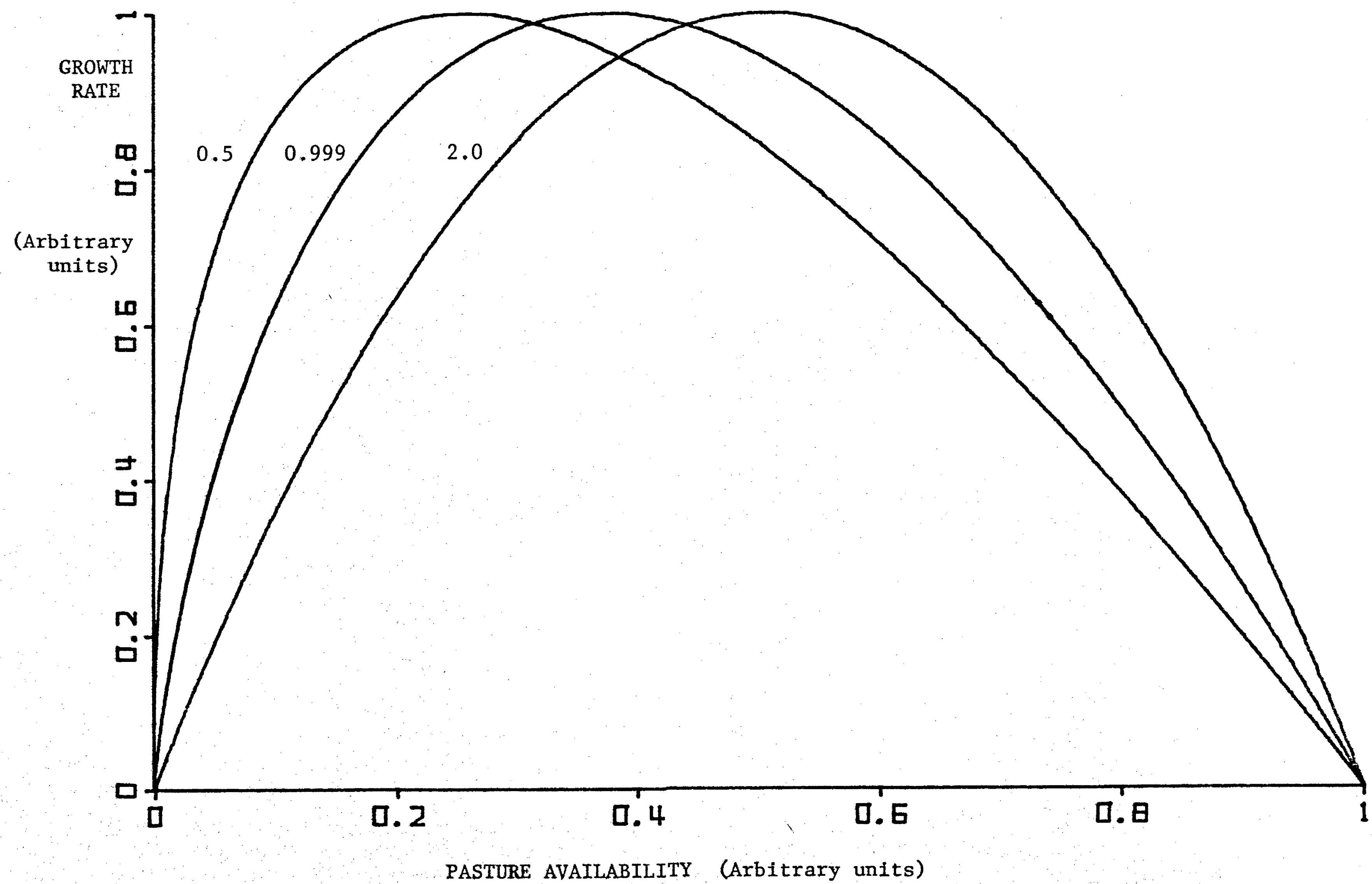

Figure 6.2 - Growth rate/availability relationships for different values of the parameter 'm' of Richards (1959) curve. Respective values of 'm' are indicated on each curve

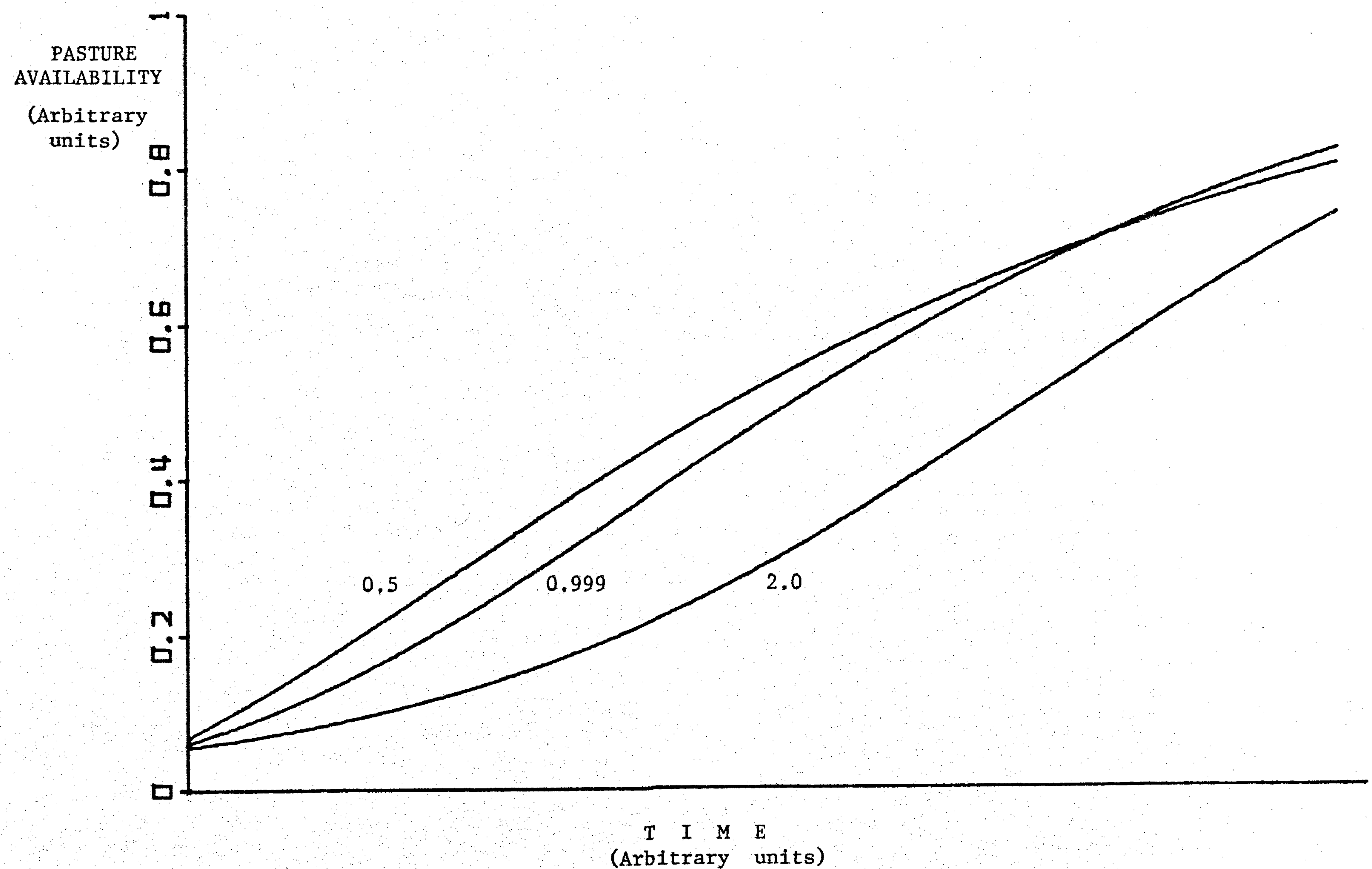

Figure 6.3 - Increase in availability with time for curves having equal maximum growth rates but different values of the parameter 'm' of Richards (1959). Respective values of 'm' are indicated on each curve

Table 6.3 - The mean effect of altering parameter RICHUD in the pasture growth equation. Values for RICHUD listed as (grass, clover) pairs

RICHUD	Stocking rate (animals ha^{-1})	Liveweight gain (kg) per hd	per ha	Fraction of kikuyu
(.5,.8)	2.5	49	123	38
(.5,.8)	4.5	22	99	35
(.5,.8)	6.5*	-27	-173	31
(.999,1.3)	2.5	37	93	32
(.999,1.3)	4.5*	4	19	26
(.999,1.3)	6.5*	-61	-394	19
(2,2)	2.5*	17	43	16
(2,2)	4.5*	-24	-107	10
(2,2)	6.5*	-89	-581	9

* "deaths" occurred in these treatments

An unexpected result was the dramatic effect that changes in the parameter RICHUD had on botanical composition. This is shown in Table 6.3 for kikuyu, although, of course, complementary changes occurred in the other species. The decreasing proportion of kikuyu as the values in array RICHUD increased is the consequence of the relatively slow growth rate of kikuyu at very low pasture availability. Kikuyu had the highest maximum growth rate and it also had the highest PASMAX value (often termed, "ceiling yield"). However, the combination of these two variables in the Richards function will not always produce a higher growth rate. Over a range of green pasture availabilites from 200-1200kg ha^{-1}, kikuyu has the highest potential growth rate for values of RICHUD within the interval (0.5, 2.0) but the relative advantage is not by any means constant for varying values of RICHUD. This point is brought out in Table 6.4, the entries of which are the potential growth rate of the different species as a percentage of the potential of kikuyu.

Table 6.4 - The potential growth rates of species other than kikuyu as a percentage of the potential growth rate of kikuyu for three settings of parameter RICHUD and over a range of pasture availabilities.

RICHUD	Pasture ($kg\ ha^{-1}$)	Carpet grass	Paspalum	White clover
0.5	200	49	86	55
0.5	400	47	85	53
0.5	600	46	84	51
0.5	800	45	84	49
0.5	1000	43	83	47
.999	200	58	91	68
.999	400	56	90	65
.999	600	53	89	62
.999	800	51	88	59
.999	1000	50	87	57
2.0	200	65	96	81
2.0	400	64	95	79
2.0	600	62	94	76
2.0	800	61	93	74
2.0	1000	59	93	72

It will be recalled that one of the factors which determine whether one species will outcompete another is its growth rate relative to the other species. Examination of Table 6.4 shows that as the values of RICHUD increase, the growth rate of kikuyu, relative to the other species, decreases. The pasture availabilities in Table 6.4 were encountered largely at high stocking rates and hence it was that the proportion of kikuyu rapidly decreased with increasing stocking rate.

From the above discussion and results presented in Table 6.3 it is clear that the the parameter RICHUD can have a considerable and widespread effect on model output. It would then follow that the accurate estimation of this parameter might be a worthwhile objective for a field study.

Sensitivity to Rainfall Run-off

In Chapter 2 the difficulties of obtaining reliable estimates of rainfall run-off were mentioned and reasons were given for constructing a model which ignored run-off unless the soil was saturated. Nonetheless, it is a fairly prominent omission from the model and therefore seemed a good candidate for senstitivity testing.

Boughton (1965) described a mathematical model for predicting run-off. The run-off routine introduced into the model encompassed the concepts advanced by Boughton except that infiltration rate was linearly related to soil moisture. Run-off was predicted from the following Fortran coding

```
        FILT    = 200 - 150*(TOTSM-WP)/FC
        RUNOFF  = RAIN*RAIN/(RAIN+FILT)
        RAINF   = RAIN - RUNOFF
```

where	FILT	= infiltration rate (mm hr^{-1})
	TOTSM	= total soil moisture (mm)
	WP	= wilting point of soil (mm)
	FC	= field capacity of soil (mm)
	RUNOFF	= run-off (mm)
	RAIN	= daily rainfall (mm)

The run-off that would result from various amounts of rain at both wilting point and field capcity is shown in Figure 6.4. Given the same daily rainfall, the infiltration rate, and hence the amount of rainfall absorbed, is greater at low soil moisture than at high levels; and the percentage of rainfall absorbed is higher with low falls of rain than with large falls.

A summary of the effects of including a run-off routine in the model are shown in Table 6.5. Results are presented for two of the three years over which the model was run. In the first year a substantial difference occurred, in the third year the difference was smaller whereas the second year (which is not summarized in Table 6.5) produced an intermediate result. The differences between years can be traced to the rainfall distribution.

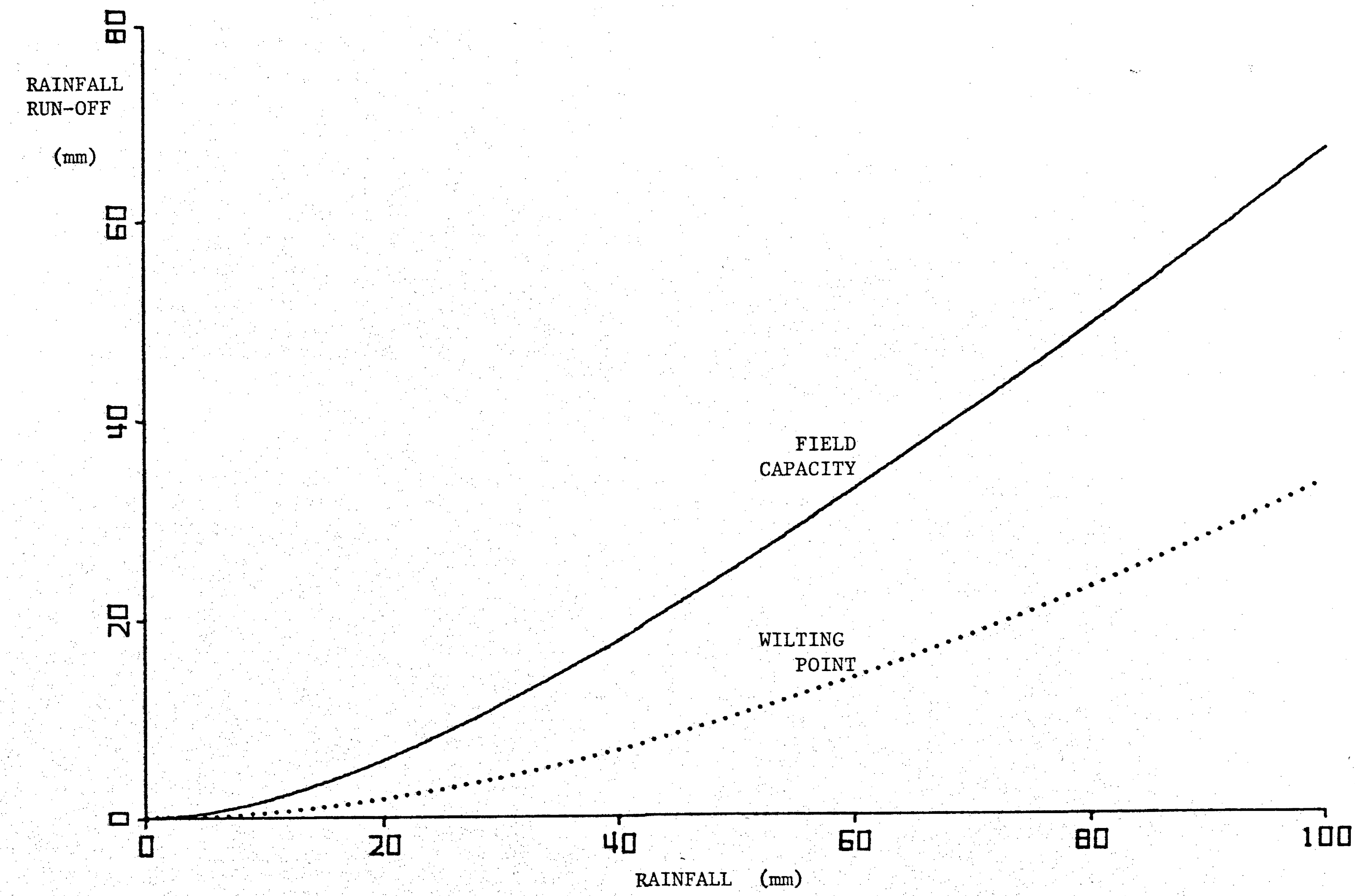

Figure 6.4 - The relationship between run-off and rainfall for soil at wilting point (dotted line) and field capacity (unbroken line)

Table 6.5 - The effect of including a rainfall run-off function in the model.

Run-off function	Stocking rate	Year	Liveweight gain (kg hd^{-1})	Pasture[a] (kg ha^{-1})
No	2.5	1	56	4724
No	2.5	3	71	4419
No	4.5	1	26	3758
No	4.5	3	41	3380
No	6.5	1	-20	3016
No	6.5	3	- 8	2603
Yes	2.5	1	27	4598
Yes	2.5	3	66	4356
Yes	4.5	1	- 5	3636
Yes	4.5	3	36	3302
Yes	6.5[b]	1	-55	2988
Yes	6.5	3	-14	2535

[a] pasture at end of year
[b] "deaths" occurred in this treatment

In year 1, the majority of the rain occurred as heavy falls. Because a proportionately greater amount of run-off results from one 50mm fall than from two falls of 25mm (Figure 6.4), a large fraction of the rain became run-off. In this year, the fact that a large amount of the rain was run-off combined with a low total fall meant that the inclusion of the run-off function caused a big difference in estimated soil moisture (Figure 6.5a). In year 3, the total rainfall was greater and when rain fell, irrespective of whether the model included the run-off function, there generally was sufficient rain for the soil to reach field capacity. Because evapotranspiration is not affected by the inclusion of a run-off function, the decline from field capacity is the same whether or not a run-off function is included in the model. Consequently, for much of the year the estimated soil moisture was the same (Figure 6.5b).

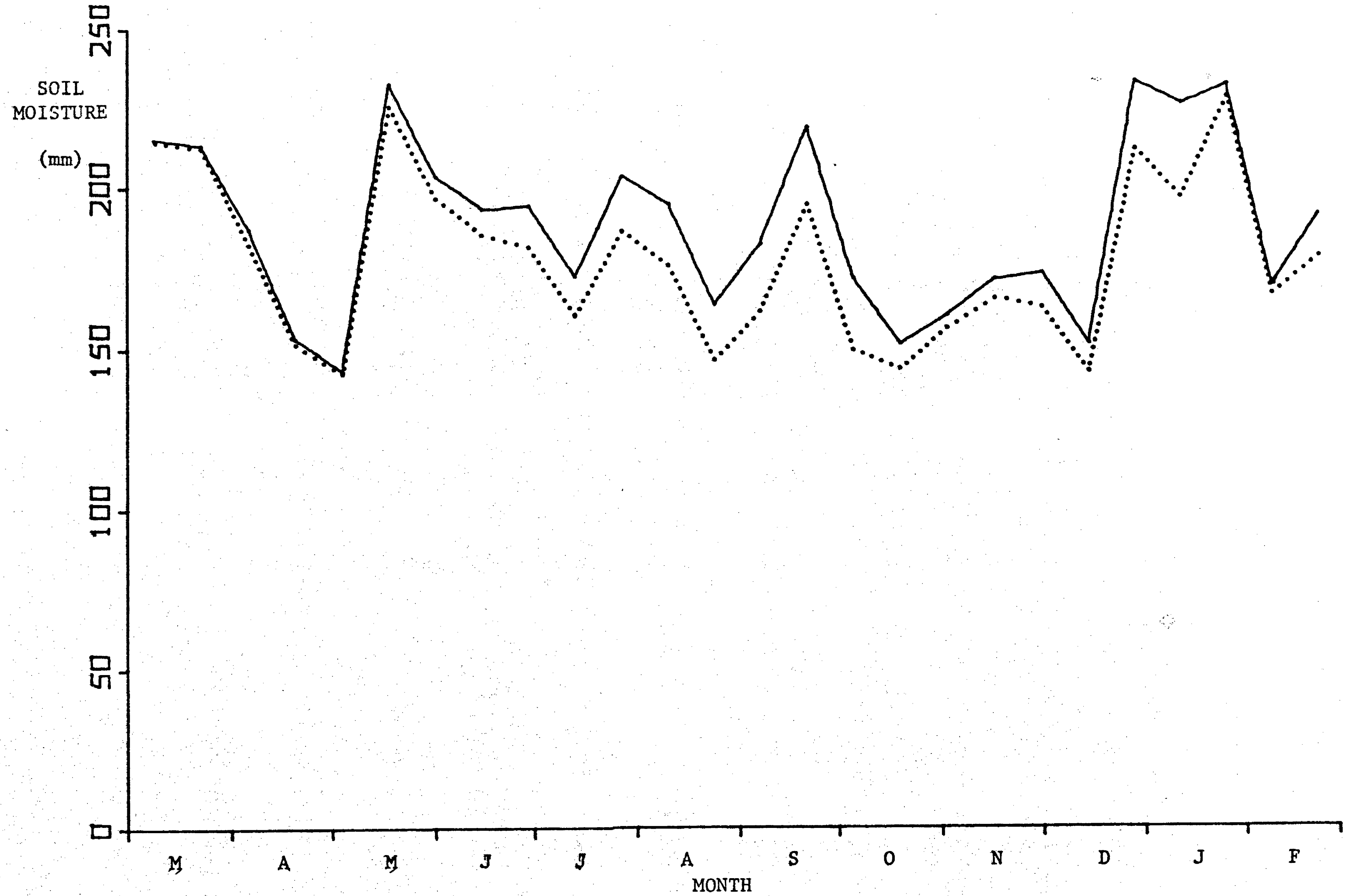

Figure 6.5a - The soil moisture profile in Year 1 of the simulation with (dotted line) and without

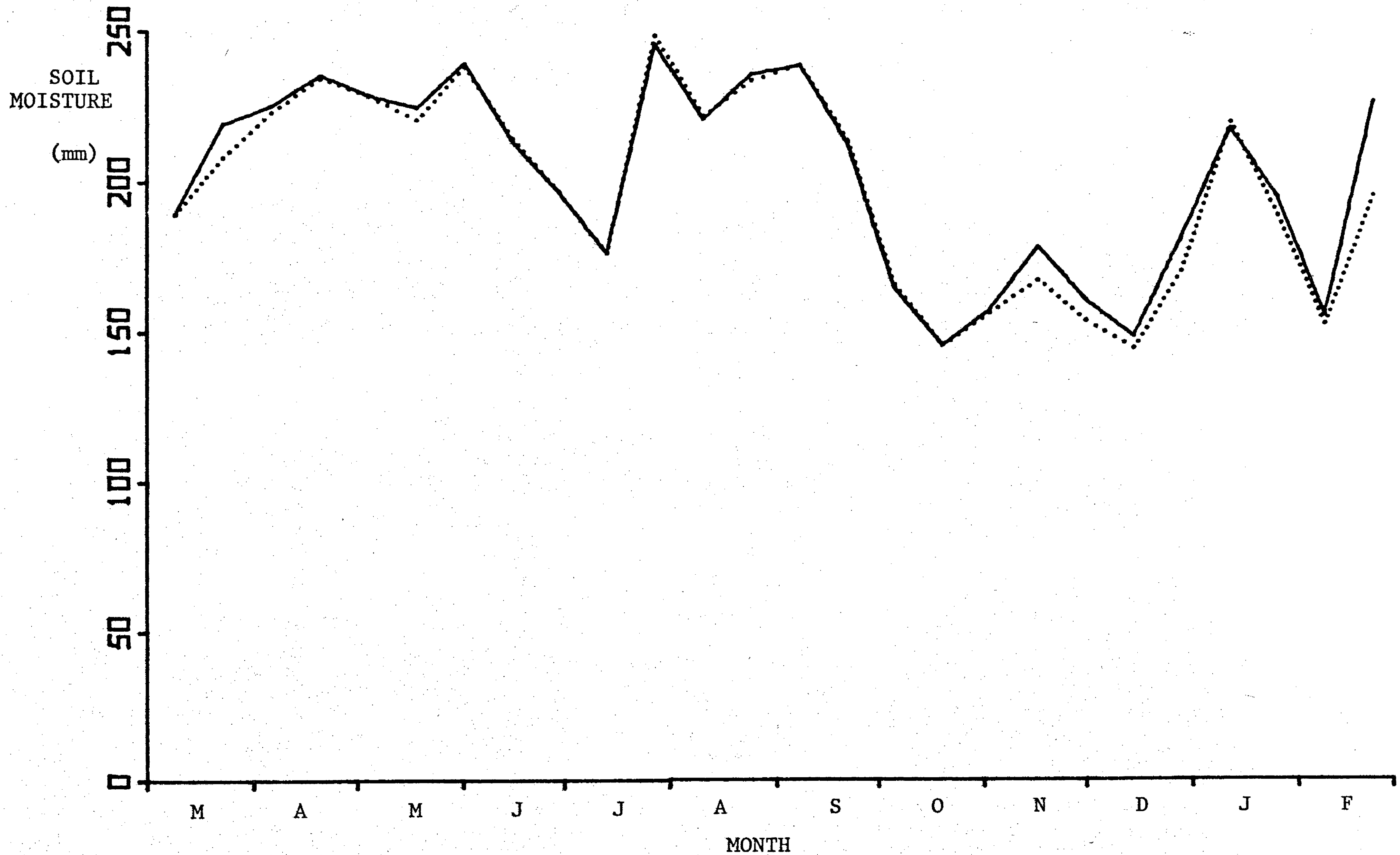

Figure 6.5b - The soil moisture profile in Year 3 of the simulation with (dotted line) and without (unbroken line) the run-off routine in the model

After having conducted the sensitivity tests, I was struck by the obviousness of the results. The fact that they were not anticipated perhaps indicates a failure on my part to see the obvious. Such failures may well be common because, after all, what is more obvious than Newton's law of of inertia ?

Modellers will always be confronted with the charge that models produce the obvious. The model of an hypothetical city described in Forrester's 1969 book, "Urban Dynamics", produced many results that he termed counterintuitive. For example, his model predicted that the provision of a retraining program for the unemployed would not be beneficial to a city because it would increase the numbers of unemployed. Two years later Kadanoff (1971) perceived that these effects were, in fact, intuitive. I have no complaint about Kadanoff's analysis. It is, however, difficult to assess after an event, what was intuitive before the event. I suspect that despite all efforts to be honest, more people could pick "from first principles" the winner of a Melbourne Cup after it had been run than before.

A further sensitivity test was conducted and its output is presented as Appendix D. This test examined the consequences of using either dairy (with a high milk production) or beef animals in a breeding system. The test was done, in part, to provide an example of the physical output obtained from the model. It was not as comprehensive as the three tests described above (stocking rate was not varied) and is not referred to elsewhere in the main text of the thesis.

System Testing

An example follows of the use to which a completed simulation model may be put. In the example the performance of systems, which have not been tested experimentally, is examined. The costs of running an experiment which could explore the parameter space examined in this test are large enough to preclude such an experiment ever being undertaken. The system test involves a comparison over three years of three times of calving x three stocking rates x three levels of nitrogen fertilizer (Table 6.6).

The nitrogen was applied as equal dressings in spring (September 1), summer (December 1) and autumn (March 1). The length of time cows and calves were run together varied, being shorter as the season progressed. Each run commenced with 150 cows, all of which were pregnant in the first year. During the second and third years the number of pregnant animals was determined in the program, following the criteria described in Chapter 4.

Table 6.6 - Treatments compared in the system test using the model. Design was a 3^3 factorial; levels of each factor and details of each level are given

Factor	Level	Description
Time of calving	1	Calving on day 151
		Breeding on day 236
		Weaning on day 60
	2	Calving on day 211
		Breeding on day 296
		Weaning on day 90
	3	Calving on day 271
		Breeding on day 356
		Weaning on day 120
Nitrogen rate(N)	1	0
(kg N $ha^{-1}yr^{-1}$)	2	150
	3	300
Stocking rate (SR)	1	SR=1,N=1; SR=2,N=2; SR=3,N=3
(breeding cows ha^{-1})	2	SR=2,N=1; SR=3,N=2; SR=4,N=3
	3	SR=3,N=1; SR=4,N=2; SR=5,N=3

An assessment of the marginal economic return and the marginal direct and indirect energy costs were made for each system. The economic return was calculated as the sum of the net change in value of each system plus the differences between trading returns and variable costs. It was necessary to sum these two components because the differences in time of calving meant that the more simply calculated gross margins would be less realistic as it would not have distinguished between animals of different physiological state at the end of a three year run. The marginal energy cost of production was calculated because of the growing awareness that the world reserves of many forms of this resource are in fact finite and hence the likely increasing importance of developing "low energy" farming systems.

For the economic analyses, 1972 prices were used. The fertilizer was assumed to be ammonium nitrate which cost $75 per ton, i.e. $0.17 per kg N (Australian Fertilizers Limited, pers. comm.). Mature cattle value (MCV,$) was assessed as a function of weight (W,kg) and the number of days pregnant (D),

$$MCV = 60 + 0.15*W + 0.08*D$$

This function yields the following predictions of MCV

W	D = 0	90	180	270
250	98	105	112	119
350	113	120	127	134
450	128	135	142	149

Calf value (CV,$) was assumed to be a function of weight (W,kg) and average liveweight change (LWC, kg) over the past two weeks

$$CV = 30 + 0.25*W + 0.5*LWC$$

Some predictions obtained from this function follow

W	LWC = -4	0	4	8
80	48	50	52	54
120	58	60	62	64
160	68	70	72	74

The costs of inputs are presented in Table 6.7. Estimates of the energy costs of production are particularly difficult to obtain because of the enormous problems in determining indirect energy costs. For example, how much of the energy used in road construction should be apportioned to an industry which uses those roads for transport of its goods? In consequence, large variations in the estimates of energy costs of production exist; Heichel (1973) provided an estimate of 6.5 Mcal (1 Mcal=1000 Kcal) for the energy cost of production of a kilogram of nitrogen fertilizer whereas Dekkers, Lange and de Wit (1974) provided an estimate of 30, Mcal. Heichel's estimate was for production "prior to blending" and the estimate of Dekkers, Lange and de Wit was for "the cost of nitrogen fertilizer production". Although it is not clear precisely what these different phrases mean, it seems implausible that they could account for the over four-fold differences in the two estimates of energy cost. Pimentel et al. (1973) gave an intermediate estimate of 18.5 Mcal for "production and processing".

Table 6.7 - Economic and energy costs used in the analyses.

Input	Unit	Cost[a]	
		Economic($)	Energy(Mcal)
Labour	hr	1.50	.36
Gasoline	litre	.10	7.98
Fertilizer[b]	kg N	.17	10.0
Machinery[c]	kg	1.50	18.5

[a] Variable costs were \$12 per breeding cow-year and \$4 per non-breeding cow-year. Using the conversion of Heichel (1973) of 17.4 Mcal $\$^{-1}$, the "energetic variable costs" are 261 and 87 Mcal for breeding and non-breeding cow-years respectively.

[b] Ferilizer was assumed to be applied by the farmer who spread it at a rate of 1.25 tonne per hour. The tractor consumed 16 litres of gasoline per hour.

[c] A machinery overhead of 4 tonnes was assumed, with those farmers involved in fertilization having an extra 2 tonnes of machinery. Machinery was assumed to last for 10 years.

Even if agreement on the costs of production could be obtained, there would still be considerable problems of interpretation. This was seen by Dekkers, Lange and de Wit (1974) who pointed out that adding up "energy from such completely different sources (as oil, electricity and milk) is rather like adding up the weights of all red objects in town". Red objects or not, the decision that needs to be made is whether an attempt at budgeting, despite its shortcomings, is better than no attempt. It is my view that the attempt is worthwhile.

The energetic data in Table 6.7 were derived largely from the work of Pimentel et al. (1973) and Heichel (1973). Some derivations are presented as footnotes to Table 6.7, the others are within the range of estimates found in the previously cited papers.

Results of the System Test

A summary of the main "treatment" effects are shown in Tables 6.8 and 6.9. The effect of altered time of calving was, in general, slight. Stocking rate changes produced the animal product changes (Table 6.8) that have been demonstrated many times in the field. Consequently, as stocking rate increased, economic return per hectare (ER, $) first increased, then decreased. The treatment which had the greatest effect was N fertilization.

Before discussing the results in detail, it should be pointed out that it was not until about the third year that a "steady state" was approached (or at least as steady a state as can be expected in a fluctuating environment). The results reported are the means of the three years, although comparisons are best made after a steady state has been reached. With a system test as large as the one conducted, it would have been expensive on computer time to have waited for a steady state. A better approach than the one used, in which all animals were pregnant in the first year, would have been to have made say, 70% of all cows pregnant in year 1. In this way the system would have taken less time to reach a steady state. Nonetheless, the differences between years were consistent for all treatments and the results reported would reflect the differences between systems at steady state.

The small but consistent increases in the number of calves born and liveweight gain ha^{-1} that occurred as time of calving was advanced are the result of higher cow weights at calving time in the mid and late calving animals as opposed to the early calving cows. The late calving cows, in general, put on weight prior to calving, and thus, when mated, their liveweights were greater and consequently the probability of pregnancy increased; hence, more calves were born. With later calving, there was lower pasture availability at the end of each year (day 275, October 2) because at this time the calves of early calving cows were consuming significant amounts of pasture whereas the calves of late calving cows were only 5 days old and were consuming no pasture.

Table 6.8 - Summary of the treatment means for several of the biological variables.

Treatment	Pasture* availability kg ha^{-1}	Number calves born yr^{-1}	Number calves dying yr^{-1}	Liveweight gain $ha^{-1}yr^{-1}$
Time of calving				
early	4025	38	2	173
mid	4161	39	1	179
late	4324	39	1	184
N fertilizer				
0	3825	36	3	102
150	3937	38	0	196
300	4749	41	0	334
Stocking rate				
low	4987	40	0	134
medium	4163	39	0	213
high	3361	36	3	234

* mean pasture availability at the end of each year

As stocking rate (SR) increased so also did liveweight gain per ha (LWGPH). Bearing in mind the usual LWGPH/SR response curves (Jones and Sandland 1974), it would seem likely that the maximum LWGPH had not been reached, yet the SR which maximized economic return (Table 6.9) had clearly been reached. This is a good example of the fact that if the variable cost per animal is constant then as stocking rate increases the economic maximum must occur before the biological maximum. Although this point can be simply demonstrated, judging by the stocking rates that are usual in agricultural experimentation, it is often overlooked.

It has been explained that the better performance of late calving animals was, in part, a consequence of the cows being at a higher liveweight at calving and mating. Thus, to an extent, the apparent advantage of late calving may be an artefact of the initial conditions of the run. It would thus seem that unless the sale price of the calves were fairly certain to be higher at some time of the year, the selection of the time of calving would not be critical, although a slight advantage could accrue from late calving.

Table 6.9 - Summary of the treatment means for several economic and energetic variables.

Treatment	Return $ ha^{-1}	Cost Mcal ha^{-1}	Return/cost
Time of calving			
early	7	2224	0.047
mid	13	2236	0.051
late	16	2241	0.054
N fertilizer			
0	44	320	0.154
150	-2	2280	-0.001
300	-5	4101	-0.002
Stocking rate			
low	-3	2021	0.066
medium	24	2250	0.060
high	16	2430	0.026

Nitrogen fertilization had the greatest effect of all the treatments on economic and energetic variables. Both the 150 and 300 kg N ha^{-1} yr^{-1} treatments resulted in a negative economic return whereas the return from no fertilizer was positive (Table 6.9). The effect on the amount of energy used was even more dramatic - over a twelve-fold difference existed in the amount of energy used per ha between the 0 and 300 kg N treatments. Time of calving had a negligible effect on energetic cost and there was a small but consistent increase in energetic cost as stocking rate increased.

The ratio ER/EC (last column in Table 6.9) is an index of the efficiency with which energy is used. It is only one of the many indices that could be used, and is relevant for the costs and returns used in this analysis. A larger value of the index indicates a more "efficient" system. The results of Table 6.9 show that the variable having the most outstanding effect on ER/EC ratio is nitrogen fertilizer. This is not surprising since N fertilization resulted in a decreased economic return and a greater energetic cost. The extent of the variation is, however, very large.

If a particular treatment has a low ER/EC ratio and its inputs use relatively large amounts of energy then, considering the recent world increases in the price of energy, such a treatment would be an extremely doubtful economic proposition. If current prices are considered rather than the 1972 prices which were used in the analyses, then this will be seen to be true; the price of nitrogen fertilizer has doubled during that period.

The major conclusion from this system test is that the application of nitrogen fertilizer to pastures is unlikely to play a role in a viable breeding system on the north coast of NSW. Changing prices will alter the economics but, because of the low ER/EC ratios for the N fertilizer treatments, it would seem unlikely that the price of cattle could change sufficiently to make the use of N fertilizer an economic proposition.

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Chapter 7

GENERAL DISCUSSION AND CONCLUSIONS

In several of the preceeding chapters various problems, relevant to the chapter in which they occurred, were discussed. This final chapter attempts to bring into perspective the more important topics already considered and how they relate to model building in general.

Several topics were discussed in Chapter 2 - "The Climate Generator". In comparison with the later problems the issues raised in Chapter 2 were fairly unimportant. Large amounts of climatic data will, in general, exist and they are usually accurately recorded. Consequently, the variances and covariances between the variables can be established and reasonably reliable climate generators constructed.

Despite the shortcomings of the method of calculation of actual evapotranspiration (E_a) and despite the simplistic soil moisture budget, the water movement routine in the model produced good agreement with Canberra data (Chapter 5). This is not to say that the calculated E_a were near to being correct, but if they were not, the underestimation and overestimation occurred in an apparently random manner. Hence, given enough soil moisture data, a reasonably well tuned moisture movement routine can probably be produced. In general, the simulation of the abiotic section of the model produced few problems, i.e. the errors that exist within it are unlikely to be important.

Chapter 3 - "The Pasture Sub-model" introduced the first of a number of awkward modelling problems. The first of these was how to represent the sward in the model. The minimum requirement was that the pasture could "age". This has ramifications in both the growth from a given weight of pasture and the quality of the diet that is selected. Although the method used in the model could reproduce the intended qualitative effects, whether it was quantitatively "near the mark" is a matter for conjecture. If, as in the model, a number of plant pools are specified each with a weighting (i.e. material in pool 1 can grow 1.2 times as fast as that in pool 2), then to get a first approximation of the weightings may not be too difficult. Estimating the weightings should be a reasonably straightforward matter of optimization; it would involve subjecting swards to a number of different treatments (e.g. temperature and moisture stress) and then determining regrowth from the differently treated swards.

An alternative approach would be to consider the sward to be composed of biologically definable, rather than conceptual pools, e.g. pools of of structural carbohydrates, soluble carbohydrates, protein etc. The plants "growth" would then be defined to be a function of the amounts in the various pools, e.g. structural carbohydrates may provide little impetus for growth compared with say, soluble carbohydrates. An advantage of this approach, as opposed to the one used in the model, is that it is more mechanistic, and thus less likely to produce absurd results when used outside the parameter space on which it has been developed. With an approach such as this, where the pools are definable plant components within the sward, the pools could be given reasonable digestibility, fibre or "chewiness", and protein contents (e.g. protein content of protein pool = 100%) rather than the arbitrary values used with each pool in this model (Chapter 4). A disadvantage of this approach would be that more information (chemical composition) must be collected along with the regrowth data in field experiments. Nonetheless, it appears to me to have much to commend it. Any approach in modelling which suffers few disadvantages but brings one nearer the mechanisms operating, is worthwhile. Only by a series of such steps is modelling separated from empirical statistical analyses.

The second major problem encountered in the pasture generator was the development of a suitable competition sub-model. The method described in Chapter 3 worked, and it should be possible to generalize it. For most pastures, it may not be possible to advance a more mechanistic approach. Numerous studies by de Wit and co-workers have investigated within- and between-species competition, yet de Wit's models are hardly mechanistic (de Wit 1960; de Wit and Bergh 1965; Brennan et al. 1970). To understand and then model the processes of plant competition requires far more study.

During the construction of this model it became apparent that little or no information existed in several areas which appeared to be potentially important. A few of the more obvious ones are the definition of pasture growth rate as a function of availability, determination of effects of temperature on plant growth rate and estimation of senescence and decay rates, and the effect of temperature, soil moisture etc., on these rates. It is important to stress that it is the rates which need to be estimated not the sizes of the state variables. Hence, shorter sampling intervals than are usually used may be more appropriate. By using short intervals, non-linearities may become more obvious. However, apart from the cost disadvantage of more frequent sampling, the size of the error in measurement relative to the variable being measured, increases. It will thus be more difficult to determine the "true" response.

There were a number of hazily defined parameters and processes in the animal sub-model. Most of the estimates of parameters used in the feed utilization component of the sub-model came from ARC (1965). The methods of determining many of these parameters, e.g. the efficiencies of utilization of metabolizable energy for processes such as maintenance, lactation etc. traditionally involve metabolism chambers and standard calorimetric methods. Such methods are extremely costly (Blaxter 1956). Recently, Newberry (1974) provided an example of how parameters can be estimated from fairly easily collected data, assuming that the model of utilization proposed by ARC (1965) is correct. Newberry's approach was new and appeared promising; it would be well worthwhile applying it to other sets of data to further evaluate the technique.

Using current techniques, the dietary composition of a grazing animal can be measured. However, a problem that exists in simulation studies is to determine what is consumed in terms of the pasture components defined in the model. In this model, and in models which define pools through which the pasture passes, it is necessary to work out a dietary selection routine. However, if selection occurs from pools that have no physical analogues it is difficult to know how to make the selection routine operate. If the alternative approach suggested in this chapter is used to define the pasture (i.e. containing pools of soluble carbohydrate, protein etc.), then it should be somewhat easier to measure from which pools the material is selected, although this approach would introduce some techinal problems such as the measurement of the release of soluble carbohydrates by mastication. Nonetheless, considering modelling of the dietary selection routine alone, there is a fairly strong argument for regarding a pasture as consisting of pools of biologically definable components rather than the arbitrary six pools defined in this model.

If, as was assumed in the model, the probability of conception is a linear function of liveweight, weight change over the past 14 days and lactational status of the animal then, in theory, there is no difficulty in finding suitable coefficients for such a function. Practical difficulties arise because the animal numbers required for even a simple experiment are enormous; assuming a 4x4x2 factorial experiment (liveweight x liveweight change x lactational status) with 25 animals per treatment cell, then 800 breeding cows are required. Even then, the estimates of the probability would, at times, have a large confidence interval; if 6 of the 25 cows in one treatment conceived then the 95% confidence interval of the probability (p) of conception would be,

$$.07 < p < .41$$

The greatest problem encountered in this study emerged during the validation phase. The problem could be put simply as the question "how do you validate a model such as the one developed in this study ?". When one is confronted with the problem of validating a particular model then the rather theoretical writings of Naylor and Finger (1967) and Phillips (1971) amongst numerous others tend to be of little use. The article of Wright (1971) provides some moral support - this may be as much help as can be obtained from the literature. It is, perhaps, pertinent that the book of Mize and Cox, which is entitled "Essentials of Simulation", has less than 2 pages devoted to validation, yet Anderson and Dent (1971) regard validation as being likely to be the key problem in systems work.

The mood of discouragement in the preceding paragraph did not develop because the data for the total model validation were poor. The experiment of Mears (1973) was well designed and conducted; the treatments covered a large region of parameter space, at each sampling a large amount of relevant data was collected and the samplings were admirably frequent. Yet, despite this, enormous difficulties were introduced into the validation attempts by random error. These were discussed in some detail in Chapter 5. The point will not be discussed again, but is mentioned in order to emphasize the difficulty random error introduces to problems of validation.

No real problems arose in the sensitivity testing phase (Chapter 6) for by that stage the problems had either been resolved or accepted. One fairly minor point became obvious: the realism introduced by incorporating stochastic elements into the model can prove a disadvantage during sensitivity testing. This comment does not apply to the climate generator but more useful output would have been obtained from the model had the number of cows conceiving been calculated as expected numbers (involving perhaps fractions of a cow) rather than as integers drawn randomly from a binomial distribution. No advantage was obtained by regarding the number conceiving as a random variable whereas the provision of the expected number would have lessened chance variation between treatments and provided a more accurate indication of the consequences of parameter changes.

It would thus be useful to include a "flag" in the model which, depending on its value, could trigger the production of either stochastic or deterministic output from various sections of the model.

The final section of Chapter 6, which incorporated the system test, provided an indication of how a model may be applied to the determination of research priorities. The fact that there may be glaring shortcomings in a model may not be relevant if it provides the only method of examining some important region of parameter space. This is not meant to imply that great weight must be placed on the output; that will surely be moderated by the shortcomings. However, the pertinent question is whether some attempt is better than none.

It is possibly fitting that this thesis should conclude on that note, for it will only be if system tests such as the one in this model provide useful information for decision making that simulation will continue to thrive in agricultural management studies. The often expressed and somewhat ethereal virtues that are, at times, ascribed to modelling will not, on their own, ensure the necessary flow of money to allow the development of simulation modelling projects.

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Appendix A

Derivation of Actual Evapotranspiration .

Nomenclature

E_t	=	daily evaporative demand or potential evapotranspiration (mm d^{-1})
E_a	=	actual evapotranspiration (mm d^{-1})
dE_m/dt	=	maximum rate at which the sward can supply moisture (mm hr^{-1})
h	=	daylength (hr)
t	=	time after sunrise (hr)
k	=	constant (mm hr^{-1})

and dE_t/dt and dE_a/dt are the rates of potential and actual evapotranspiration (mm hr^{-1}) respectively.

1. Assuming evaporative demand follows a sine curve

Evaporative demand will be defined as

$$dE_t/dt = k.\sin(\pi t/h) \tag{1}$$

Integrating both sides over the daylength yields

$$E_t = \int_0^h k.\sin(\pi t/h)dt$$
$$= 2kh/\pi$$

Hence, $k = \pi E_t/2h$

Now the maximum value (1) can take is k , hence if dE_m/dt is greater than k then the plant can meet the environmental demand for the whole day and $E_a = E_t$.

If $dE_m/dt < k$ then for part of the day the environmental demand will exceed the plant's ability to supply moisture. If the time at which $dE_m/dt = dE_t/dt$ is called c and c is constrained to be less than h/2, then by arguments of symmetry

$$E_a = 2\left\{\int_0^c k.\sin(\pi t/h)dt + dE_m/dt.(h/2-c)\right\} \tag{2}$$

Now at $t = c$, $dE_m/dt = k.\sin(\pi c/h)$

or $\arcsin(dE_m/dt/k) = \pi c/h$

whence, $c = h.\arcsin(dE_m/dt/k)/\pi$

The solution to (2) can now be directly calculated to be

$$\begin{aligned} E_a &= 2kh/\pi - 2kh.\cos(\arcsin(dE_m/dt/k))/\pi \\ &\quad + h.dE_m/dt - 2h.dE_m/dt.\arcsin(dE_m/dt/k)/\pi \\ &= E_t - E_t.\cos(\arcsin(2h.dE_m/dt/(\pi E_t))) \\ &\quad + h.dE_m/dt \\ &\quad - 2h.dE_m/dt.\arcsin(2h.dE_m/dt/(\pi E_t))/\pi \qquad (3) \end{aligned}$$

2. Assuming evaporative demand follows the pattern defined by Fleming (1970)

The pattern of demand described by Fleming (1970) was that of a truncated triangle. Thus, the results of Fleming imply that the instantaneous demand will be given by the following function.

Time(t)	dE_t/dt
0 to .06h	0
.06h to .26h	$6.75(t/h-.06)E_t/h$
.26h to .80h	$1.35E\ /h$
.80h to h	$6.75(1-t/h)E_t/h$

The maximum environmental demand occurs between .26h and .80h and is $1.35E_t/h$. Thus, if $dE_m/dt \geq 1.35E_t/h$ then $E_a = E_t$.

If $dE_m/dt < 1.35E_t/h$ then for part of the day the environmental demand will exceed the rate at which the plant can supply moisture. Now, as the function described by Fleming is symmetrical about t = .53h, then when the maximum rate at which the plant can supply moisture equals the environmental demand rate, we have

$$dE_m/dt = 6.75(t/h-.06)E_t/h$$

or

$$t = h(.06+h.dE_m/dt/(6.75E_t))$$

Call this value of t, t*, then by arguments of symmetry

$$\begin{aligned} E_a &= 2hdE_m/dt((t^*h-.06)/2 + (.53-t^*/h)) \\ &= dE_m/dt((t^*-.06h) + (1.06h-2t^*)) \\ &= dE_m/dt(h-t^*) \end{aligned}$$

Substituting the above value to t* will yield

$$E_a = dE_m/dt.h(.94-h.dE_m/dt/(6.75E_t)) \qquad (4)$$

Now, (4) is clearly a very much simpler expression than (3) and because both (3) and (4) yield similar predictions of E_a, the simpler function has been used in the model. The following table demonstrates the similarity of the answers obtained from functions (3) and (4).

h	E_t	dE_m/dt	E_a from equation (3)	(4)
10	6	.5	4.1	4.1
10	12	.8	6.9	6.7
12	6	.5	4.7	4.8
12	9	.7	6.8	6.7
12	12	.8	8.0	7.9
12	15	.9	9.2	9.0
14	12	.8	9.0	9.0
14	15	.9	10.4	10.3
14	15	1.2	12.8	12.3
14	15	1.5	14.5	15.0

Note that the estimates obtained from (3) and (4) vary in their ranking for different values of h, E_t and dE_m/dt. The constraint that E_a must be at least as large as $.035E_t$ is also applied, although this constraint would only operate rarely.

Appendix B

The Relationship between Plant Growth and Temperature

In subroutine SINSOL, the constants necessary to define the temperature/growth response curve are calculated. The general shape of the curve is shown in Figure 3.2. SINSOL is entered with the temperatures at which growth commences, maximizes and ceases (A, B and C respectively). Four constants (A1, B1, A2, B2) are calculated in SINSOL so that the following function is defined

Argument(X)	Value of function (f(X))
$X \le A$	0
$A < X \le B$	(SIN(A1*X+B1)+1)/2
$B < X \le C$	(SIN(A2*X+B2)+1)/2
$X > C$	0

The values of A1 and B1 are calculated as follows:

When $X=A,\ f(X)=0$

thus $SIN(A1*X+B1)=-1$

or $A1*X+B1 = -\pi/2$ (1)*

and when $X=B,\ f(X)=1$

thus $SIN(A1*X+B1) = 1$

or $A1*X+B1 = \pi/2$ (2)

Substituting X=A in (1) and X=B in (2) and subtracting (1) from (2) yields

$A1*(B-A) = \pi$

hence $A1 = \pi/(B-A)$

---

* The solution suggested to equation (1), (2), (3) and (4) is merely a convenient one. Clearly the value on the right side of the relation e.g. $-\pi/2$ in (1), could equally be replaced by $2n-\pi/2$, where n is any integer. Such a change in any or all of these equations would not affect the validity of the above derivations nor the predictions from the derivations.

Using this result in (1) yields

$$\pi * A/(B-A) + B1 = -\pi/2$$

hence $$B1 = \pi * (A/(A-B) - .5)$$

Calculation of A2 and B2 follows a similar pattern.

when $X=B,\ f(X) = 1$

thus $SIN(A2*X+B2) = 1$

or $$A2*X + B2 = \pi/2 \tag{3}$$

and when $X=C,\ f(X) = 0$

thus $SIN(A2*X+B2) = -1$

or $$A2*X+B2 = -\pi/2 \tag{4}$$

Substituting X=B in (3) and X=C in (4) and subtracting (4) from (3) yields

$$A2*(B-C) = \pi$$

hence $$A2 = \pi/(B-C)$$

$$\pi*B/(B-C)+B2 = \pi/2$$

hence $$B2 = \pi*(B/(C-B)+.5)$$

APPENDIX C

The Model Listing

```
      SUBROUTINE CLISIM(KMONTH)
C
C  **  SUBROUTINE CLISIM IS THE SUBROUTINE RESPONSIBLE FOR GENERATING THE
C      CLIMATIC CONDITIONS OF EACH DAY. IT CALLS A NUMBER OF SLAVE SUBROUTINES
C      AND FUNCTION SUBPROGRAMS TO ACHIEVE THIS END
C
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION RN(10)
      DATA RN/.2159,.068,.9227,.009,-.4948,
     *        .5702,.0962,-.1337,.019,-1.1352/
      PR(Z,KSUB)=RN(KSUB+1)+RN(KSUB+2)*SIN(Z+RN(KSUB+3))
     *                     +RN(KSUB+4)*SIN(2.*Z+RN(KSUB+5))
      POTEVP(TEMP,Z)=3.28+.111*TEMP+.00101*TEMP*TEMP
     *        -1.134*SIN(Z-1.29)-1.12*KPREV
C
C    VARIABLE           MEANING
C
C      AMTSM    VARIABLE USED TO CALCULATE NEW SOIL MOISTURE AFTER EVAPOTRANSN
C      CARRY    AMT OF MOISTURE TRANSFERED FROM TOP TO BOTTOM SOIL LAYER
C        CK     MAXIMUM HOURLY EVAPORATIVE DEMAND
C       DIFF    DIFFERENCE BETWEEN SOIL MOISTURE AND FIELD CAPACITY (MM)
C        DL     DAYLENGTH
C        EL     INTERMEDIATE VARIABLE IN CALCULATION OF ACTUAL EVAPOTRANS
C       EMP     INTERMEDIATE VARIABLE IN TEMP CALC, CAUSES TIME CORRELATION
C      EVACT    ACTUAL EVAPOTRANSPIRATION
C      EVPOT    POTENTIAL EVAPOTRANSPIRATION
C     EXCESS    EXTRA RAIN BEYOND THAT WHICH GIVES SATURATION TO TOP SOIL LAYER
C     EXRAIN    EXPECTED RAINFALL
C     EXTEMP    EXPECTED TEMPERATURE
C        FC     FIELD CAPCITY (FRACTION)
C       FC1     FIELD CAPACITY (MM) OF TOP SOIL LAYER
C       FC2     FIELD CAPCITY (MM) OF BOTTOM SOIL LAYER
C       FS1     FIELD SATURATION (MM) OF TOP SOIL LAYER
C       FS2     FIELD SATURATION (MM) OF BOTTOM SOIL LAYER
C     HORIZD    DEPTH (CM) OF SOIL LAYERS
C      KPREV    =0 IMPLIES NO RAIN THAT DAY; =1 IMPLIES RAIN
C      LEVEL    =1 (TOP) OR =2(BOTTOM),DEFINING LAYER FROM WHICH WATER IS DRAWN
C        NSD    =3 ON DAY OF RAIN,=2 DAY AFTER,=1 TWO DAYS AFTER ETC.
C     PENMAN    PARAMETER IN RANGE (.6,.8) DEFINING EVPOT FROM PAN EVAPORATION
C        PRR    PROBABILITY OF RAIN
C       RAIN    AMT OF RAIN (MM)
C        RAN    RANDOM NUMBER
C      RATIO    ACTUAL/POTENTIAL EVAPOTRANSPIRATION
C     REMAIN    AMT WATER (MM) REMAINING ABOVE FIELD CAPCITY
C         RN    CONSTANTS USED IN ESTIMATION OF PRR(ARRAY)
C     SDTEMP    STD DEV OF TEMPERATURE
C         SM    SOIL MOISTURE (FRACTION)
C        SM1    SOIL MOISTURE IN TOP SOIL LAYER (MM)
C        SM2    SOIL MOISTURE IN BOTTOM SOIL LAYER (MM)
C     SUMMON    MONTHLY AVERAGES OF SEVERAL CLIMATIC VARIABLES
C       TEMP    TEMPERATURE
C      TOTSM    TOTAL SOIL MOISTURE
C      TRMAX    MAXIMUM TRANSPIRATION RATES OF SOIL LAYERS
C        TRR    ACTUAL TRANSPIRATION RATES (MAX) FROM EACH SOIL LAYER
C         WP    WILTING POINT (FRACTION) OF SOIL LAYERS
C          Z    DAY OF YEAR * 2 * PI / 365, USED IN SINE FUNCTIONS
C
```

```
C  RAINFALL GENERATION
C
      KSUB=5*KPREV
      PRR=PR(Z,KSUB)
      RAN=RANF(-1)
      IF(PRR.GT.RAN)GO TO 30
      KPREV=0
      EXRAIN=0.0
      RAIN=0.0
      GO TO 100
   30 KPREV=1
      EXRAIN=12.83+2.67*SIN(Z-.02)-1.05*SIN(2.*Z-1.24)
      RAIN=RAINRV(Z )*EXRAIN
      SUMMON(1,KMONTH)=SUMMON(1,KMONTH)+RAIN
C
C  TEMPERATURE DISTRIBUTION ASSUMED TO BE NORMAL
C  THOM,H.C.S.(1973)ARCH.MET.GEOPH,BIOKL.,SER. B,21:43-54
C
  100 EXTEMP=18.718+4.6122*SIN(Z+1.2873)+.5908*SIN(2.*Z-1.5122)
      SDTEMP=5.319-.6285*SIN(Z-.9265)+.7473*SIN(2.*Z-1.3956)
     *                                  +.4955*SIN(3.*Z-.3802)
      RAN=ANORM(0)
      EMP=EXTEMP+SDTEMP*RAN*1.7321
      TEMP=(TEMP+EMP)/2.
      SUMMON(6,KMONTH)=SUMMON(6,KMONTH)+TEMP
C
C  CALCULATION OF POTENTIAL EVAPOTRANSPIRATION AND ACTUAL EVAPOTRANSPIRATIO
C
      EVPOT=POTEVP(TEMP,Z)*PENMAN
      SUMMON(4,KMONTH)=SUMMON(4,KMONTH)+EVPOT
      LEVEL=1
C
C  A MAXIMUM TRANSPIRATION RATE OF 1.50 MM/HR IS BASED ON THE PAPER BY
C  VAN BAVEL(1966),WATER RESOURCES RESEARCH 2:455
C
      DO 120 I=1,2
      IF(SM(I).GE.FC(I))GOTO 110
      TRR(I)=(SM(I)-WP(I))/(FC(I)-WP(I))*TRMAX(I)
      GOTO 120
  110 TRR(I)=TRMAX(I)
  120 CONTINUE
      IF(TRR(1).LT.TRR(2))LEVEL=2
C
C  THE FOLLOWING FUNCTION WHICH DEFINES DAYLENGTH IS THE REGRESSION
C  OF VALUES DETERMINED FROM THE SUBROUTINE PRESENTED BY FITZPATRICK
C  IN GRAZING SYSTEMS NEWSLETTER, R**2=.9992
C
      DL=11.97-1.785*SIN(Z-1.4045)-.0373*SIN(2.*Z-1.561)
      CK=1.35*EVPOT/DL
      IF(TRR(LEVEL).GE.CK) GOTO 130
      EL=TRR(LEVEL)*DL*DL/(6.75*EVPOT)+.06*DL
      EVACT=TRR(LEVEL)*(DL-EL)
      GOTO 140
  130 EVACT=EVPOT
  140 EVACT=AMAX1(EVACT,.035*EVPOT)
      RATIO=EVACT/EVPOT
      SUMMON(3,KMONTH)=SUMMON(3,KMONTH)+RATIO
      SUMMON(5,KMONTH)=SUMMON(5,KMONTH)+EVACT
C
C  SOIL MOISTURE BUDGET
C
      AMTSM=SM(LEVEL)*HORIZD(LEVEL)
      AMTSM=AMTSM-EVACT
      SM(LEVEL)=AMTSM/HORIZD(LEVEL)
      CARRY=0.0
      SM1=SM(1)*HORIZD(1)
      SM2=SM(2)*HORIZD(2)
      IF(KPREV.EQ.0)GOTO 300
      IF(RAIN+SM1.GT.FC1)GOTO 210
      SM1=SM1+RAIN
      GOTO 300
  210 IF(RAIN+SM1.GT.FS1)GOTO 220
      SM1=SM1+RAIN
      NSD(1)=3
      GOTO 300
  220 EXCESS=RAIN+SM1-FS1
      SM1=FS1
      NSD(1)=3
      IF(EXCESS+SM2.GT.FC2)GOTO 230
      SM2=SM2+EXCESS
      GOTO 300
```

```
  230 IF(EXCESS+SM2.GT.FS2)GOTO 240
      NSD(2)=3
      SM2=SM2+EXCESS
      GOTO 300
  240 NSD(2)=3
      SM2=FS2
  300 NSD(1)=NSD(1)-1
      NSD(2)=NSD(2)-1
      IF(NSD(1))310,320,320
  310 IF(SM1.GT.FC1)SM1=FC1
      GOTO 335
  320 IF(SM1-FC1)310,310,330
  330 DIFF=SM1-FC1
      REMAIN=.3*DIFF
      CARRY=DIFF-REMAIN
      SM1=FC1+REMAIN
  335 IF(NSD(2))340,350,350
  340 IF(SM2.GT.FC2)SM2=FC2
      GOTO 380
  350 IF(SM2-FC2)380,380,360
  360 EXCESS=FC2-SM2
      REMAIN=.3*EXCESS
      SM2=FC2+REMAIN
  380 SM2=SM2+CARRY
      IF(SM2.LT.FS2)GOTO 400
      SM2=FS2
      NSD(2)=3
  400 TOTSM=SM1+SM2
      SUMMON(2,KMONTH)=SUMMON(2,KMONTH)+TOTSM
      SM(1)=SM1/HORIZD(1)
      SM(2)=SM2/HORIZD(2)
      RETURN
      END
```

```
      SUBROUTINE PASTYA
C
C  **  SUBROUTINE PASTYA GENERATES ANY NEW PASTURE AND HANDLES THE TRANSFER
C      OF OLDER PASTURE TO DIFFERENT POOLS, PLUS THE DECAY OF DEAD PASTURE
C
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
C         ARRAY
C       SUBSCRIPT            SPECIES
C           1          CARPET GRASS(AXONOPUS AFFINIS)
C           2          PASPALUM    (PASPALUM DILATATUM)
C           3          KIKUYU      (PENNISETUM CLANDESTINUM)
C           4          WHITE CLOVER(TRIFOLIUM REPENS)
C
C
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C   VARIABLE          MEANING
C
C       A        DEFINES CEILING YIELD AS IN RICHARDS(1959)
C       AI       WEIGHTING FACTOR WHICH DEFINES THE GROWTH ABILITY OF PASTURE COMP
C       AK       RATE CONSTANT, EQUIVALENT TO K OF RICHARDS(1959)
C       AM       PARAMETER OF GROWTH EQN. EQUIVALENT TO 1.-M OF RICHARDS(1959)
C     AMTRAN     AMOUNT OF PASTURE TRANSFERED FROM ONE COMPONENT CLASS TO ANOTHER
C     CRITDL     CRITICAL DAYLENGTH, IF EXCEEDED REPROD STARTS IN SPECIES 1 AND 2
C      DECAY     PASTURE DECAY RATE (I.E. TRANSFER OF DEAD TO HUMUS)
C     DECAYF     VARIABLE TO CONTROL OVERALL RATE OF DECAY IN GRASSES AND CLOVER
C       DK       ACTUAL DECAY IN KG/HA
C     FACTOR     INTERMEDIATE VARIABLE
C      FERTF     FERTILIZER FACTOR. DEFINED BY VALUE OF FP,FN AND SPECIES
C       GRO      MAXIMUM PLANT GROWTH RATE - ONLY USED IN INITIAL CHECK RUNS
C     GROTH      MAXIMUM GROWTH RATE OF PASTURE SPECIES
C     NPADOC     INDEX OR FLAG DEFINING PADDOCK NO.
C     NPADOK     NUMBER OF PADDOCKS USED IN THIS RUN
C     NSPECY     INDEX OR FLAG DEFINE SPECIES
C     PASMAX     UPPER LIMIT TO AMOUNT OF PASTURE THAT CAN BULK-UP IN I-TH SPECIES
C     PGROTH     PASTURE GROWTH RATES
C      PLANT     AMOUNT OF DRY MATTER IN I-TH COMPONENT,J-TH SPECIES IN K-TH PADDK
C       PRK      RATE CONSTANTS FOR PASTURE SPECIES. EQUIVALENT TO RICHARDS K
C      RATIO     ACTUAL/POTENTIAL EVAPOTRANSPIRATION
C     REPROF     FACTOR TO INCREASE SENESCENCE OR DECREASE DECAY DUE TO FLOWERING
C     RICHUD     PARAMETER OF GROWTH EQUATION. EQUIVALENT TO M PARAMETER,RICHARDS
C     SENESC     RATE OF SENESCENCE OF CLOVER
C     SENESF     VARIABLE TO CONTROL OVERALL RATE OF SENESCENCE IN GRASSES AND CLV
C     SENESS     ACTUAL SENESCENCE (KG/HA)
C     SENEST     RATE OF SENESCENCE OF TROPICALS
C     TEMFAC     CONSTANTS DEFINE RESPONSE CURVE OF PLANT TO TEMPERATURE
C      TEMP      TEMPERATURE
C      TEMPF     TEMPERATURE FACTOR SEE ALSO FERTF
C     TEMPLF     ESTIMATED TEMPERATURE OF LEAF
C      TOTSM     TOTAL SOIL MOISTURE
C       W        GREEN DRY MATTER AVAILABLE
C     WATCAP     MOISTURE HOLDING CAPACITY OF SOIL AT FIELD CAPACITY AND SATURATN
C
      CRITDL=13.0
      TEMPLF=0.74*TEMP+9.0
      TEMPLF=TEMPLF+1.0*(EVPOT-EVACT)
      SENESC=0.00225*TEMP-0.030*RATIO
      SENESC=AMAX1(0.008,SENESC)
      IF(TEMP.GT.9.0)GOTO 110
C
C  THE EFFECT OF FROSTING ON THE TROPICAL GRASSES
C
      SENEST=9.0-TEMP
      SENEST=.08+.015*SENEST
      GOTO 120
  110 SENEST=SENESC*0.90
  120 FACTOR=TOTSM/WATCAP(2)
      DO 140 NSPECY=1,4
      TEMPF=HUMP(TEMFAC(NSPECY,1),TEMFAC(NSPECY,2),TEMFAC(NSPECY,3),
     *TEMFAC(NSPECY,4),TEMFAC(NSPECY,5),TEMFAC(NSPECY,6),
     *TEMFAC(NSPECY,7),TEMPLF)
      DO 140 NPADOC=1,NPADOK
      W=0.0
C
C  ADJUSTMENT FOR THE PHOTOSYNTHATE PRODUCING ABILITY OF THE DIFFERENT POOLS
C
      DO 132 I=1,4
      AI=1.25-.1*I
  132 W=W+AI*PLANT(I,NSPECY,NPADOC)
C
C  GROWTH RATE =
C                                     (1-M)
C                         K*W*((A/W)       -1)
C                         --------------------
C                                 (1-M)
C
      A=PASMAX(NSPECY)
      AM=1.0-RICHUD(NSPECY)
      AK=PRK(NSPECY)
      GROTH=(A/W)**AM-1.0
      GROTH=AK*W*GROTH/AM
      CALL FERTAL(NSPECY,NPADOC)
      PGROTH(NSPECY,NPADOC)=GROTH*RATIO*FERTF*TEMPF
      SENESS=SENEST
```

```
      IF(NSPECY.NE.4)GOTO 134
      SENESS=SENESC
      PGROTH(NSPECY,NPADOC)=PGROTH(NSPECY,NPADOC)
     *     *(.25+.75*EXP(-3.0E-8*PTOTAL(NPADOC)**2))
  134 IF(DL.LT.CRITDL)GOTO 136
      IF(NSPECY.GT.2)GOTO 136
      FLORMX=PASMAX(NSPECY)*.3
      W=0.0
C
C  PLANT(I,,) FOR I=1,4 HOLDS THE AMOUNT OF GREEN LEAF DRY MATTER IN 4 POOLS
C                 I=5   HOLDS THE AMOUNT  OF DRY MATTER(LEAF + INFLORESCENCE)
C                 I=6   HOLDS THE AMOUNT OF GREEN INFLORESENCE FROM SPECIES I
C
      DO 135 I=1,5
  135 W=W+PLANT(I,NSPECY,NPADOC)
      FLORTE=1.0-EXP(-3.0*W/PASMAX(NSPECY))
      IF(PLANT(6,NSPECY,NPADOC).GT.FLORMX)FLORTE=0.0
      AMTRAN=FLORTE*PGROTH(NSPECY,NPADOC)
      PLANT(6,NSPECY,NPADOC)=PLANT(6,NSPECY,NPADOC)+AMTRAN
      PGROTH(NSPECY,NPADOC)=PGROTH(NSPECY,NPADOC)-AMTRAN
      FLORTE=1.0+.5*PLANT(6,NSPECY,NPADOC)/FLORMX
      SENESS=SENEST*FLORTE
  136 DO 138 I=2,5
      AMTRAN=PLANT(I-1,NSPECY,NPADOC)*SENESS
      PLANT(I,NSPECY,NPADOC)=PLANT(I,NSPECY,NPADOC)+AMTRAN
  138 PLANT(I-1,NSPECY,NPADOC)=PLANT(I-1,NSPECY,NPADOC)-AMTRAN
      PLANT(1,NSPECY,NPADOC)=PLANT(1,NSPECY,NPADOC)
     *                       +PGROTH(NSPECY,NPADOC)
      DECAY=.0025*KPREV+.00020*FACTOR*TEMP
      DECAY=DECAY*PTOTAL(NPADOC)/3000.
      DCAY=DECAY
      IF(NSPECY.EQ.4)DCAY=2.0*DECAY
      PLANT(5,NSPECY,NPADOC)=(1.0-DCAY)*PLANT(5,NSPECY,NPADOC)
      AMTRAN=PLANT(6,NSPECY,NPADOC)*SENESS*0.25
      PLANT(5,NSPECY,NPADOC)=PLANT(5,NSPECY,NPADOC)+AMTRAN
      PLANT(6,NSPECY,NPADOC)=PLANT(6,NSPECY,NPADOC)-AMTRAN
  140 CONTINUE
      DO 150 I=1,NPADOK
      FERTAN(I)=FERTAN(I)+PGROTH(4,I)*.00005*PERCEN(4,I)
  150 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FERTIL(I,J)
C  **  SUBROUTINE FERTIL RETURNS THE VALUE OF FERTF, THE FERTILIZER FACTOR.
C      THE VALUE OF FERTF IS DIFFERENT FOR EACH PASTURE SPECIES FOR THE SAME
C      VALUES OF FN AND FP.
C
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION AN(4),BN(4),CN(4),AP(4),BP(4),CP(4)
      DATA AN/.4,.1,.05,.7/,
     1     BN/2.5,2.5,1.5,4./,
     2     CN/2.0,3.0,4.0,1.0/,
     3     AP/3*0.95,.3/,
     4     BP/3*4.,2./,
     5     CP/3*1.,2.5/
      FNFERT(A,B,C,F)=A+(1.-A)*(1.-EXP(-B*F**C))
C
C   VARIABLE           MEANING
C
C      DK      ACTUAL DECLINE IN FERTILITY DUE TO TIME
C    DKCONN    DECAY CONSTANT FOR NITROGEN DECLINE
C    DKCONP    DECAY CONSTANT FOR PHOSPHOROUS DECLINE
C    FERTAN    ACTUAL N FERTILITY OF SOIL
C    FERTAP    ACTUAL P FERTILITY OF SOIL
C     FERTF    FERTILIZER FACTOR, DEFINED BY VALUE OF FP,FN AND SPECIES
C     FERTN    INITIAL N FERTILITY
C     FERTP    INITIAL P FERTILITY
C      FN      VALUE OF FERTAN USED IN CALCULATIONS
C      FP      VALUE OF FERTAP USED IN CALCULATIONS
C     RESN     RESPONSE BY I-TH SPECIES TO LEVEL OF SOIL NITROGRN
C    RESNMX    MAXIMUM VALUE FNFERT CAN TAKE WITH I-TH SPECIES AND F=FN
C     RESP     RESPONSE BY I-TH SPECIES TO LEVEL OF SOIL PHOSPHOROUS
C    RESPMX    MAXIMUM VALUE FNFERT CAN TAKE WITH I-TH SPECIES AND F=FP
C
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      DKCONP=.0015
      DKCONN=.0060
      FERTAP(J)=FERTAP(J)-FERTP(J)
C
C  EXPONENTAIAL DECAY FROM EXISTING LEVEL OF SOIL FERTILITY TO 'BASE' LEVEL
C  THE ACTUAL RATE OF DECAY BEING DETERMINED BY VARIABLES DKCONP AND DKCONN
C
      DK=FERTAP(J)*DKCONP
      FERTAP(J)=FERTAP(J)-DK+FERTP(J)
      FERTAN(J)=FERTAN(J)-FERTN(J)
      DK=FERTAN(J)*DKCONN
      FERTAN(J)=FERTAN(J)-DK+FERTN(J)
      GOTO 180
C
C  A CALL IS MADE TO FERTZ AT THE COMMENCEMENT OF EACH RUN SO THAT THE
C  VALUES OF RESNMX AND RESPMX CAN BE DEFINED
C
      ENTRY FERTZ
      RESPMX(I)=FNFERT(AP(I),BP(I),CP(I),1.0)
      RESNMX(I)=FNFERT(AN(I),BN(I),CN(I),1.0)
      GOTO 180
      ENTRY FERTAL
      FN=AMIN1(FERTAN(J),1.0)
      FP=AMIN1(FERTAP(J),1.00)
      ENTRY SUMREE
      RESN=FNFERT(AN(I),BN(I),CN(I),FN)
      RESP=FNFERT(AP(I),BP(I),CP(I),FP)
      FERTF=RESP*RESN/(RESNMX(I)*RESPMX(I))
  180 RETURN
      END
```

```
      SUBROUTINE COMPET
C
C  **  THIS SUBROUTINE DETERMINES THE SIZE OF THE BOTANICAL COMPOSITION
C      CHANGES FOR EACH DAY  THE DECISION AS TO HOW LARGE THE CHANGE WILL BE
C      DEPENDS ON BOTH THE GROWTH OF THE SPECIES AND ITS GROWTH HABIT
C
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      DIMENSION SPPFAC(4),CVRMAX(4),CVRMIN(4),CHANGE(4),SPPQ(4)
      DATA SPPFAC/4.5,4.4,-9.0,27.0/,CVRMIN/4*.01/,CVRMAX/4*.9/,
     *     SPPQ/-3.1,-3.1,40.,-35./
C
C   VARIABLE          MEANING
C
C    CHANGE   VARIABLE USED IN CALCS TO DETERMINE BUT COMPOSITION CHANGES
C    COMFAC   RATE CONSTANT DEFINE HOW FAST CHANGES OCCUR
C    CVRMAX   MAXIMUM AMOUNT OF GROUND THAT CAN BE COVERED BY THE I-TH SPECIES
C    CVRMIN   MINIMUM AMOUNT OF GROUND THAT CAN BE COVERED BY THE I-TH SPECIES
C    NPADOK   NO, PADDOCKS ON THIS RUN. MUST BE LESS THAN 5
C    PERCEN   FRACTION OF GROUND COVER OCCUPIED BY I-TH SPECIES IN J-TH PADDOC
C    PGROTH   PASTURE GROWTH RATES
C    SPPFAC   A VARIABLE WHICH CONSIDERS PLANT MORPHOLOGY IN COMPETITION
C    TGROTH   TOTAL PASTURE FROWTH
C    TOTCH    AN INTERMEDIATE VARIABLE USED IN CALCULATIONS
C
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      DO 100 N=1,NPADOK
      TGROTH=0.0
      DO 10 I=1,4
   10 TGROTH=TGROTH+PGROTH(I,N)*PERCEN(I,N)
      IF(TGROTH.LT.1E-5)GOTO 100
      TOTCH=0.0
      DO 40 I=1,4
      PR=(PERCEN(I,N)-CVRMIN(I))/(CVRMAX(I)-CVRMIN(I))
      PR=EXP(-2.0*PR*PR)*(SPPFAC(I)+FERTAN(N)*SPPQ(I))
      IF(I.NE.4)GOTO 30
C
C  THE SENSITIVITY OF CLOVER TO DRY SPELLS
C
      R=RATIO-0.6
      PR=2.0*PR*R*R
      PR=SIGN(PR,R)
   30 CHANGE(I)=PGROTH(I,N)*PR
      TOTCH=TOTCH+CHANGE(I)
   40 CONTINUE
      CHGPOS=0.0
      CHGNEG=0.0
      COMFAC=0.00003
      COMFAC=COMFAC*(1.0-0.5*(1.0-EXP(-.0002*TGROTH**2)))
C
C  THE FOLLOWING DO-LOOP CONSIDERS IF A PLANT IS GROWING MORE ACTIVELY THAN
C  THE AVERAGE FOR THAT DAY. IF SO, DEPENDING ON SPECIES, A WEIGHTING IS PUT
C  ON ITS GROWTH TO DETERMINE THE RATE OF INGRESS TO OTHER SPECIES.
C  THUS SPPFAC CONSIDERS GROWTH HABITS IN COMPETITION.
C
      DO 60 I=1,4
      CHANGE(I)=CHANGE(I)-TOTCH/4.0
      CHANGE(I)=CHANGE(I)*COMFAC
      IF(CHANGE(I).LT.0.0)GOTO 50
      IF(PERCEN(I,N).LT.CVRMAX(I))GOTO 55
      CHANGE(I)=-CHANGE(I)
      GOTO 58
   55 CHGPOS=CHGPOS+CHANGE(I)
      GOTO 60
   50 IF(PERCEN(I,N).GT.CVRMIN(I))GOTO 58
      CHANGE(I)=-CHANGE(I)
      GOTO 55
   58 CHGNEG=CHGNEG+CHANGE(I)
   60 CONTINUE
      IF(ABS(CHGNEG).LT.1E-8)GOTO 100
      DO 80 I=1,4
      IF(CHANGE(I).LT.0.0)GOTO 70
      PERCEN(I,N)=PERCEN(I,N)+CHANGE(I)
      GOTO 80
   70 PERCEN(I,N)=PERCEN(I,N)-CHANGE(I)*CHGPOS/CHGNEG
   80 CONTINUE
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EATUP
C
C  **  SUBROUTINE EATUP CALCULATES THE PASTURE,HAY AND GRAIN CONSUMPTION OF AL
C      CLASSES OF ANIMAL. IT THEN PROCEEDS TO EVALUATE THE EFFICIENCY OF FEED
C      CONVERSION FOR WHATEVER PROCESSES ARE INVOLVED. .EATUP. ALSO DETERMINES
C      WHAT WEIGHT GAINS ARE MADE AND THE MILK PRODUCTION OF LACTATING COWS.
C
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
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      DIMENSION GR(6),HY(6),FASTHP(6),EMAINT(6),EWALK(6),ELEVEL(6),
     *EPROD(6),ENGMAX(6),FIBMAX(6),QM(6),POTHAY(6)
      DATA EM/.82/,EDM/4.39/,DIGRN/.80/,DIGHY/.65/,
     *     FIBGRN/30./,FIBHAY/100./,DMILK/.13/,DIGMLK/.9/
     *,GRAINN/1.5/,HAYN/1.4/,PRNC/6.25/,BV/.75/,ECMILK/.76/
      CAL(A,B)=1.425+.00365*A+.231*EFFICF*ABS(B)
     *            +0.00011*A*EFFICF*ABS(B)
      PREGN(N,W)=.00005851*EXP(.03*N)*(W+178.8)+.00749*W
C
C THE CLASSES OF ANIMAL CONSIDERED AND THE POSITION THEY TAKE IN ARRAYS ARE
C                      NUMBER        CLASS
C                        1           STEERS
C                        2           DRY COWS - EMPTY
C                        3           DRY COWS - PREGNANT
C                        4           LACTATING COWS - EMPTY
C                        5           LACTATING COWS - PREGNANT
C                        6           UNWEANED CALVES
C
C   VARIABLE          MEANING
C
C    ACTMLK     ACTUAL MILK PRODUCTION OF THE I-3TH CLASS,J PADDOCK
C     AREA      AREA OF EACH PADDOCK
C    AVAILF     FACTOR WHICH LIMITS INTAKE IF AVAILABILITY IS LOW
C    AVMILK     AVERAGE AMOUNT OF MILK PRODUCED BY LACTATING COWS
C    AWOOD      PARAMETER OF WOOD(1968) MILK PRODUCTION CURVE = WOOD'S A
C      BV       BIOLOGICAL VALUE OF PROTEIN FOR CATTLE
C    CALVWG     CALORIFIC VALUE OF WEIGHT CHANGES
C    DAIRYN     NITROGEN OUTPUT IN MILK
C     DCP       DIGESTIBLE CRUDE PROTEIN
C    DEPRES     DEPRES IN DIET METABILIZABILITY IF LEVEL OF FEEDING GREATER THAN1
C    DIETN      NITROGEN CONCENTRATION IN PASTURE CONSUMED
C     DIFF      DIFFERENCE BETWEEN ENERGY NEEDED FOR MAX MILK PROD AND AVAIL ENGY
C    DIGEST     DIGESTIBILITY OF COMSUMED PASTURE
C    DIGHY      DIGESTIBILITY OF HAY
C    DIGRN      DIGESTIBILITY OF GRAIN
C    DIGMLK     DIGESTIBILITY OF THE DRY MATTER IN MILK
C     DMI       DRY MATTER INTAKE
C    DMILK      DRY MATTER CONTENT OF MILK
C     EAVL      ENERGY AVAILABLE TO COW AS CALF CANT COMSUME ALL MILK
C    ECMILK     ENERGY CONTENT OF MILK
C     EDM       ENERGY PER KG DRY MATTER
C    EFFDIV     AN INTERMEDIATE VARIABLE TO CALCULATE EFFICM
C    EFFICF     EFFICIENCY OF ULTILIZATION OF ME FOR FATTENING OR WT LOSS
C    EFFICL     EFFICIENCY OF UTILIZATION OF ME FOR LACTATION
C    EFFICM     EFFICIENCY OF UTILIZATION OF ME FOR MAINTENANCE
C    EFFICW     EFFICIENCY OF UTILIZATION OF ME FOR WALKING
C    ELEVEL     APPROXIMATE LEVEL OF INTAKE,USED TO RECALCULATE QM
C      EM       METABOLIZABLE ENERGY AS A FRACTION OF DIGETIBLE ENERGY
C    EMAINT     ENERGY REQ'D FOR MAINTENANCE
C     EMET      METABOLIZABLE ENERGY CONSUMED BY CLASS I
C    ENDOGN     ENDOGENOUS NITROGEN EXCRETED IN URINE
C    ENERGY     METABOLIZABLE ENERGY OF CONSUMED PASTURE (MCAL/KG)
C    ENGMAX     MAXIMUM METABOLIZABLE ENERGY INTAKE OF THE I-TH CLASS
C    EPROD      ENERGY REMAINING (+VE OR -VE) FOR PRODUCTIVE PRUPOSES
C     ERED      REDUCTION IN ENERGY INTAKE IF NITROGRN REQ. NOT MET BY DIET
C     EREQ      ENERGY REQUIRED FOR MAXIMUM MILK PRODUCTION
C    EWALK      ENERGY REQ'D FOR WALKING (.100 MCAL/100KG/MILE)
C    FASTHP     FASTING HEAT PRODUCTION FOR I-TH CLASS
C    FECALN     AMOUNT OF NITROGEN EXCRETED IN FAECES
C    FIBGRN     CHEWINESS OF GRAIN
C    FIBHAY     CHEWINESS OF HAY
C    FIBMAX     MAXIMUM AMOUNT OF 'CHEWINESS' THE I-TH CLASS OF ANIMAL CAN TAKE
C    FIBRE      CHEWINESS OF CONSUMED FEED
C    FLACT      FACTOR BY WHICH LACTATING COWS CAN INCREASE INTAKE
C    FPREG      FACTOR BY WHICH PREGNANT COWS CAN INCREASE INTAKE
C    FRCINT     FRACTION OF DIETERY INTAKE,INDEX CORRESPONDS TO DMD AND FC
C      GR       AMT GRAIN FOR EACH CLASS
C    GRAIN      AMT GRAIN FED TO I-TH PADDOCK
C    GRAINN     NITROGEN CONCENTRATION IN GRAIN
C    GRENG      TOTAL METABOLIZABLE ENERGY SUPPLIED BY GRAIN
C    HAIRN      NITROGEN LOST IN HAIR AND SCURF
C     HAY       AMT HAY FED TO I-TH PADDOCK
C     HAYN      NITROGEN CONCENTRATION IN HAY
C    HEATRQ     AMOUNT OF ENERGY REQUIRED TO MET MAINTENANCE DEMANDS
C      HY       AMT HAY FOR I-TH CLASS
C     ITR       COUNTER OF NUMBER OF ITERATIONS WHEN DEFINING NITROGEN INTAKE
C    NPADOK     NUMBER OF PADDOCKS USED IN THIS RUN
C    NDPREG     NUMBER OF DAYS PREGNANT FOR CLASS 3 OR 5 COWS IN THE J-TH PDK
C    NOANIM     NO. ANIMALS IN THE I-TH CLASS,GRAZING THE J-TH PADDOCK
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C     PASINT    PASTURE DRY MATTER INTAKE
C     PASRED    REDUCTION IN PASTURE INTAKE IF NITROGEN REQ. ARE NOT MET BY DIET
C     PERCEN    FRACTION OF GROUND COVER OCCUPIED BY I-TH SPECIES IN J-TH PADDOCK
C     PLANT     AMOUNT OF DRY MATTER IN I-TH COMPONENT,J-TH SPECIES IN K-TH PADDK
C     POTHAY    POTENTIAL INTAKE OF HAY FOR I-TH CLASS OF ANIMAL
C     POTYLD    POT MILK PROD FOR CLASS 4 OR 5 IN J-TH PADDOCK
C     PROPRV    PROTEIN PROVIDED BY DIET
C     PTOTAL    TOTAL PASTURE DRYMATTER
C       Q       MET. ENERGY OF PASTURE AS A FRACTION OF GROSS ENERGY
C       QM      MET. ENERGY OF DIET OF I-TH CLASS AS A FRACTION OF GROSS ENERGY
C     REDINT    REDUCTION IN INTAKE BECAUSE NITROGEN REQ. ARE NOT MET
C     REDUCN    REDUCN IN MILK YIELD CAUSED BY LOW ME INTAKE
C     TOTENG    TOTAL ENERGY REQUIRED IF ALL DIET IS GRAIN
C     TOTHAY    TOTAL HAY REQUIRED IF ALL REMAINDER OF DIET IS HAY
C     TOTNRQ    TOTAL NITROGEN REQUIRED TO MEET THE PRODUCTION ATTAINABLE
C     TOTPRQ    TOTAL PROTEIN REQUIRED TO MEET THE PRODUCTION ATTAINABLE
C     WALK      NO MILES WALKED PER DAY
C       WT      WEIGHT(KG) OF THE I-TH CLASS OF ANIMAL IN THE J-TH PADDOCK
C      WTCH     AN INTERMEDIATE VARIABLE TO CALCULATE WTGAIN
C     WTGAIN    DAILY WEIGHT GAIN
C     YLDMAX    MAXIMUM MILK YIELD THAT COULD BE OBTAINED
C
      DO 400 N=1,NPADOK
      CALL SELECT(N)
      DO 10 I=1,6
      IF(NOANIM(I,N).GT.0)GOTO 15
   10 CONTINUE
      GOTO 400
   15 Q=DIGEST(N)*EM
      ENERGY(N)=Q*EDM
      WALK=2400.+3200.*EXP(-.0005*PTOTAL(N))
      DO 150 I=1,6
      PASINT(I,N)=0.0
      HY(I)=0.0
      GR(I)=0.0
      IF(NOANIM(I,N).EQ.0)GOTO 150
C
C  ADJUSTING ENGMAX AND FIBMAX VALUES DEPENDING ON PHYSIOLOGICAL STATE
C
      GOTO(60,70,70,70,70,80),I
   60 FIBMAX(I)=40.00+1.70*WT(I,N)*EXP(-.0010*WT(I,N))
      ENGMAX(I)=.250*WT(I,N)**.75
      GOTO 150
   70 FIBMAX(I)=35.00+1.65*WT(I,N)*EXP(-.0011*WT(I,N))
      ENGMAX(I)=.240*WT(I,N)**0.75
      GOTO(150,150,100,90,90),I
   80 IF(WT(I,N).GT.150.)GOTO 60
      ENGMAX(I)=.315*WT(I,N)**.75
      FIBMAX(I)=15.00+1.25*WT(I,N)*EXP(-.0020*WT(I,N))
      GOTO 150
   90 FLACT=(POTYLD(I-3,N)/YLDMAX(N))*.4+1.0
      ENGMAX(I)=ENGMAX(I)*FLACT
      FIBMAX(I)=FIBMAX(I)*FLACT
      IF(I.EQ.4)GOTO 150
  100 IF(NDPREG(N).LE.240)GOTO 150
      FPREG=1.0-0.0025*(NDPREG(N)-240.0)
      ENGMAX(I)=ENGMAX(I)*FPREG
      FIBMAX(I)=FIBMAX(I)*FPREG
  150 CONTINUE
C
C  ALLOCATION OF GRAIN IF IT IS BEING FED
C
      IF(GRAIN(N).LE..5)GOTO 200
      TOTENG=0.0
      DO 155 I=1,5
      IF(NOANIM(I,N).EQ.0)GOTO 155
      TOTENG=TOTENG+ENGMAX(I)*NOANIM(I,N)
  155 CONTINUE
      GRENG=GRAIN(N)*DIGRN*EM*EDM
      IF(GRENG.LT.TOTENG)GOTO 165
      DO 160 I=1,5
      IF(NOANIM(I,N).EQ.0)GOTO 160
      GR(I)=ENGMAX(I)/(DIGRN*EM*EDM)
      ENGMAX(I)=0.0
  160 GRAIN(N)=GRAIN(N)-GR(I)*NOANIM(I,N)
      GOTO 250
```

```
  165 DO 170 I=1,5
      IF(NOANIM(I,N).EQ.0)GOTO 170
      GR(I)=(ENGMAX(I)/(DIGRN*EM*EDM))*GRENG/TOTENG
      ENGMAX(I)=ENGMAX(I)-GR(I)*DIGRN*EM*EDM
      FIBMAX(I)=FIBMAX(I)-GR(I)*FIBGRN
  170 CONTINUE
      GRAIN(N)=0.0
C
C  ALLOCATION OF HAY IF IT IS BEING FED
C
  200 IF(HAY(N).LE..5)GOTO 250
      TOTHAY=0.0
      DO 210 I=1,5
      IF(NOANIM(I,N).EQ.0)GOTO 210
      POTHAY(I)=AMIN1(FIBMAX(I)/FIBHAY,ENGMAX(I)/(DIGHY*EM*EDM))
      TOTHAY=TOTHAY+POTHAY(I)*NOANIM(I,N)
  210 CONTINUE
      IF(TOTHAY.LE.HAY(N))GOTO 230
      DO 220 I=1,5
      IF(NOANIM(I,N).EQ.0)GOTO 220
      HY(I)=POTHAY(I)*HAY(N)/TOTHAY
      FIBMAX(I)=FIBMAX(I)-FIBHAY*HY(I)
      ENGMAX(I)=ENGMAX(I)-HY(I)*DIGHY*EM*EDM
  220 CONTINUE
      HAY(N)=0.0
      GOTO 250
  230 DO 240 I=1,5
      IF(NOANIM(I,N).EQ.0)GOTO 240
      HY(I)=POTHAY(I)
      HAY(N)=HAY(N)-HY(I)*NOANIM(I,N)
      FIBMAX(I)=0.0
  240 CONTINUE
C
C  CALCULATION OF DIET METABOLIZABILITIES AND PASTURE INTAKE OF CLASSES 1 T
C
  250 DO 270 I=1,5
      IF(NOANIM(I,N).EQ.0)GOTO 270
      FIBMAX(I)=FIBMAX(I)*AVAILF(N)
      ENGMAX(I)=ENGMAX(I)*AVAILF(N)
      PASINT(I,N)=AMIN1(FIBMAX(I)/FIBRE(N),ENGMAX(I)/ENERGY(N))
      QM(I)=(PASINT(I,N)*Q+GR(I)*DIGRN*EM+HY(I)*DIGHY*EM)
     *                   /(PASINT(I,N)+GR(I)+HY(I))
      EMET(I)=QM(I)*EDM*(PASINT(I,N)+GR(I)+HY(I))
  270 CONTINUE
C
C  DETERMINING HEAT PRODUCTION, ENERGY REQUIRED FOR WALKING AND ANY DEPRESS
C  EFFECTS OF A FEEDING LEVEL GREATER THAN ONE
C
      DO 290 I=1,6
      EFFICM=.546+.3*QM(I)
      EFFDIV=EFFICM
      IF(NOANIM(I,N).EQ.0)GOTO 290
      FASTHP(I)=75.5+80.5*EXP(-.00400*WT(I,N))
      EMAINT(I)=FASTHP(I)*(WT(I,N)**.73)/1000.
      IF(I.EQ.6)EFFDIV=.75
      EMAINT(I)=EMAINT(I)/EFFDIV
      IF(I.EQ.3.OR.I.EQ.5.AND.NDPREG(N).GT.250)EMAINT(I)=EMAINT(I)*1.2
      EFFICW=.8*EFFDIV
      EWALK(I)=0.55*WT(I,N)*WALK*1.0E-6/EFFICW
      IF(I.EQ.6)GOTO 290
      ELEVEL(I)=EMET(I)/(EMAINT(I)+EWALK(I))
      DEPRES=0.418*(ELEVEL(I)-1.0)/(QM(I)*4.39)
      DEPRES=AMIN1(1.0,1.0+0.11*(ELEVEL(I)-1.0)-DEPRES)
      QM(I)=QM(I)*DEPRES
      EMET(I)=EMET(I)*DEPRES
      EPROD(I)=EMET(I)-EMAINT(I)-EWALK(I)
  290 CONTINUE
C
C  CALCULATION OF THE LIVEWEIGHT GAINS OF NON-LACTATING ANIMALS
C
      DO 300 I=1,3
      IF(NOANIM(I,N).EQ.0)GOTO 300
      ENDOGN=.12+.186*EXP(-.015*WT(I,N))
      ENDOGN=ENDOGN*WT(I,N)**.73
      HAIRN=.02*WT(I,N)**.73
      ITR=0
  292 DMI=GR(I)+HY(I)+PASINT(I,N)
      PROPRV=HAYN*HY(I)+GRAINN*GR(I)+DIETN(N)*PASINT(I,N)
      CP=PROPRV*PRNC/DMI
      DCP=-4.96+1.01*CP
      DCP=DCP*DMI*10.
      FECALN=5.0*DMI
      EFFICF=.85
      IF(EPROD(I).GT.0.0)EFFICF=.81*QM(I)+0.03
```

```
      CALVWG=CAL(WT(I,N),EPROD(I))
      WTGAIN(I,N)=EPROD(I)*EFFICF/CALVWG
      GAINN=25.0*WTGAIN(I,N)
      TOTNRQ=ENDOGN+HAIRN+FECALN+GAINN
      TOTPRQ=TOTNRQ*PRNC/BV
      IF(I.EQ.3)TOTPRQ=TOTPRQ+PREGN(NDPREG(N),WT(I,N))
      IF(TOTPRQ.LE.DCP)GOTO 295
      IF(ITR.EQ.3)GOTO 295
      ITR=ITR+1
      REDINT=.4*(1.0-DCP/TOTPRQ)
      PASRED=REDINT*PASINT(I,N)
      PASINT(I,N)=PASINT(I,N)-PASRED
      ERED=Q*PASRED*EDM
      EMET(I)=EMET(I)-ERED
      EPROD(I)=EPROD(I)-ERED
      GOTO 292
  295 WT(I,N)=WT(I,N)+WTGAIN(I,N)
  300 CONTINUE
C
C  CALCULATION OF THE LIVEWEIGHT GAINS OF LACTATING ANIMALS
C
      DO 340 I=4,5
      IF(NOANIM(I,N).EQ.0)GOTO 340
      EFFICL=.5+.3*QM(I)
      CALL MILK(I,N)
      EREQ=POTYLD(I-3,N)*ECMILK/EFFICL
      IF(EPROD(I).GE.EREQ)GOTO 310
C
C  IN THE LACTATING COW THE MILK PRODUCTION IS REDUCED IF INSUFFICIENT
C  ENERGY FOR PRODUCTION EXISTS,THE POTENTIAL FOR PRODUCTION IS ALSO
C  REDUCED,ALTHOUGH TO A MUCH LESSER EXTENT. THIS IS ACHIEVED BY
C  ALTERING THE VALUE OF THE PARAMETER AWOOD
C
      DIFF=EREQ-EPROD(I)
      REDUCN=EXP(-0.03*DIFF*DIFF)
      REDUCN=AMAX1(REDUCN,0.5)
      ACTMLK(I-3,N)=POTYLD(I-3,N)*REDUCN
      AWOOD(I-3,N)=AWOOD(I-3,N)*(0.99+REDUCN*0.01)
      EREQ=ACTMLK(I-3,N)*ECMILK/EFFICL
      EPROD(I)=EPROD(I)-EREQ
      GOTO 320
  310 ACTMLK(I-3,N)=POTYLD(I-3,N)
      EPROD(I)=EPROD(I)-EREQ
  320 EFFICF=.85
      ENDOGN=.12+.186*EXP(-.015*WT(I,N))
      ENDOGN=ENDOGN*WT(I,N)**.73
      HAIRN=.02*WT(I,N)**.73
      DAIRYN=7.20*ACTMLK(I-3,N)
      ITR=0
  305 DMI=GR(I)+HY(I)+PASINT(I,N)
      PROPRV=HAYN*HY(I)+GRAINN*GR(I)+DIETN(N)*PASINT(I,N)
      CP=PROPRV*PRNC/DMI
      DCP=-4.96+1.01*CP
      DCP=DCP*DMI*10.
      FECALN=5.0*DMI
      IF(EPROD(I).GT.0.0)EFFICF=.81*QM(I)+0.03
      CALVWG=CAL(WT(I,N),EPROD(I))
      WTGAIN(I,N)=EPROD(I)*EFFICF/CALVWG
      GAINN=25.0*WTGAIN(I,N)
      TOTNRQ=ENDOGN+HAIRN+FECALN+GAINN+DAIRYN
      TOTPRQ=TOTNRQ*PRNC/BV
      IF(I.EQ.5)TOTPRQ=TOTPRQ+PREGN(NDPREG(N),WT(I,N))
      IF(TOTPRQ.LE.DCP)GOTO 330
      IF(ITR.EQ.3)GOTO 330
      ITR=ITR+1
      REDINT=.4*(1.0-DCP/TOTPRQ)
      PASRED=REDINT*PASINT(I,N)
      PASINT(I,N)=PASINT(I,N)-PASRED
      ERED=Q*PASRED*EDM
      EMET(I)=EMET(I)-ERED
      EPROD(I)=EPROD(I)-ERED
      GOTO 305
  330 WT(I,N)=WT(I,N)+WTGAIN(I,N)
  340 CONTINUE
      I=6
      IF(NOANIM(I,N).EQ.0)GOTO 393
      AVMILK =       (ACTMLK(1,N)*NOANIM(4,N)+ACTMLK(2,N)*NOANIM(5,N))
     1        /(NOANIM(4,N)+NOANIM(5,N))
      EMET(I)=ECMILK*(AVMILK)
      IF(ENGMAX(I).GE.EMET(I))GOTO 360
      DIFF=EMET(I)-ENGMAX(I)
      EMET(I)=ENGMAX(I)
C
C  RETURNING EXCESS MILK TO THE COWS - THIS WILL CAUSE A WEIGHT GAIN ONLY
C
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      DO 350 I=4,5
      IF(NOANIM(I,N).EQ.0)GOTO 350
      EAVL=DIFF/EFFICL
      EFFICF=.85
      IF(WTGAIN(I,N).GT.0.0)EFFICF=.94*QM(I)-.08
      CALVWG=CAL(WT(I,N),ABS(EAVL))
      WTCH=EAVL*EFFICF/CALVWG
      WTGAIN(I,N)=WTGAIN(I,N)+WTCH
      WT(I,N)=WT(I,N)+WTCH
  350 CONTINUE
      I=6
      ENGMAX(I)=0.0
      EMET(I)=EMET(I)*DIGMLK*EM
      EFFICF=0.85
      GOTO 381
C
C  CALCULATION OF CALF INTAKE OF GRAIN, HAY AND PASTURE
C
  360 ENGMAX(I)=ENGMAX(I)-EMET(I)
      IF(GRAIN(N).LE..5)GOTO 370
      GR(I)=AMIN1(ENGMAX(I)/(DIGRN*EM*EDM),FIBMAX(I)/FIBGRN,GRAIN(N)
     *        /NOANIM(I,N))
      ENGMAX(I)=ENGMAX(I)-GR(I)*DIGRN*EM*EDM
      FIBMAX(I)=FIBMAX(I)-GR(I)*FIBGRN
      GRAIN(N)=GRAIN(N)-GR(I)*NOANIM(I,N)
  370 IF(HAY(N).LT..5)GOTO 380
      HY(I)=AMIN1(ENGMAX(I)/(DIGHY*EM*EDM),FIBMAX(I)/FIBHAY,HAY(N)/
     1NOANIM(I,N))
      ENGMAX(I)=ENGMAX(I)-HY(I)*DIGHY*EM*EDM
      FIBMAX(I)=FIBMAX(I)-HY(I)*FIBHAY
      HAY(N)=HAY(N)-NOANIM(I,N)*HY(I)
  380 PASINT(I,N)=AMIN1(ENGMAX(I)/ENERGY(N),FIBMAX(I)/FIBRE(N))
      PASINT(I,N)=PASINT(I,N)*AVAILF(N)
      EMET(I)=AVMILK*ECMILK*DIGMLK*EM+PASINT(I,N)*ENERGY(N)
     1        +(GR(I)+HY(I))*EM*EDM
      EPROD(I)=EMET(I)-EMAINT(I)-EWALK(I)
      ENDOGN=.12+.186*EXP(-.015*WT(I,N))
      ENDOGN=ENDOGN*WT(I,N)**.73
      HAIRN=.02*WT(I,N)**.73
      ITR=0
  382 DMI=GR(I)+HY(I)+PASINT(I,N)+AVMILK*DMILK
      PROPRV=HAYN*HY(I)+GRAINN*GR(I)+DIETN(N)*PASINT(I,N)+AVMILK*0.6
      CP=PROPRV*PRNC/DMI
      DCP=-4.96+1.01*CP
      DCP=DCP*DMI*10.
      FECALN=5.0*DMI
      EFFICF=.85
      IF(EPROD(I).LT.0.1)GOTO 381
      IF(PASINT(I,N).LE.0.5)GOTO 381
      QM(I)=(Q*PASINT(I,N)+GR(I)*DIGRN*EM+HY(I)*DIGHY*EM)/
     1       (PASINT(I,N)+GR(I)+HY(I))
      EPAS=0.81*QM(I)+0.03
      EFFICF=(EPAS*(PASINT(I,N)+GR(I)+HY(I)) +EFFICF*AVMILK*DMILK)/
     1        (PASINT(I,N)+GR(I)+HY(I)+AVMILK*DMILK)
C
C  CALCULATION OF CALF LIVEWEIGHT GAIN
C
  381 CALVWG=CAL(WT(I,N),EPROD(I))
      WTGAIN(I,N)=EPROD(I)*EFFICF/CALVWG
      GAINN=25.0*WTGAIN(I,N)
      TOTNRQ=ENDOGN+HAIRN+FECALN+GAINN
      TOTPRQ=TOTNRQ*PRNC/BV
      IF(TOTPRQ.LE.DCP)GOTO 385
      IF(ITR.EQ.3)GOTO 385
      ITR=ITR+1
      REDINT=.4*(1.0-DCP/TOTPRQ)
      PASRED=REDINT*PASINT(I,N)
      PASINT(I,N)=PASINT(I,N)-PASRED
      ERED=Q*PASRED*EDM
      EMET(I)=EMET(I)-ERED
      EPROD(I)=EPROD(I)-ERED
      GOTO 382
  385 WT(I,N)=WT(I,N)+WTGAIN(I,N)
C
C  REMOVAL OF PASTURE BY THE GRAZING ANIMAL
C
  393 DO 394 I=1,6
      IF(NOANIM(I,N).EQ.0)GOTO 394
      FSR=PASINT(I,N)*NOANIM(I,N)/AREA(N)
      DO 392 J=1,4
      DO 392 K=1,6
  392 PLANT(K,J,N)=(PLANT(K,J,N)*PERCEN(J,N)-FSR*FRCINT(K,J))
     *               /PERCEN(J,N)
  394 CONTINUE
  400 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SELECT(N)
C
C  **  SUBROUTINE SELECT CALCULATES THE BOTANICAL COMPOSITION OF CONSUMED
C      PASTURE, IT ALSO CALCULATES THE DIGESTIBILITY AND 'BULK' OF THE DIET
C
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADDK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION PLANTN(6,4),FACN(4),NAMEN(6),BASE(6)
      DIMENSION PREF(6,4),COMPON(6),DIET(6,4),DMD(6,4),CHEW(6,4),COMP(6)
      DATA NAMEN/8H LEAF 1 ,8H LEAF 2 ,8H LEAF 3 ,8H LEAF 4 ,
     *     8H   DRY   ,8HINFLORES/
      DATA FACN/1.4,1.3,2.7,0.5/,BASE/4*50.,2*400./
      DATA(PLANTN(1,J),J=1,4)/1.42,2.65,1.36,3.90/,
     *    (PLANTN(2,J),J=1,4)/1.19,2.24,1.22,3.45/,
     *    (PLANTN(3,J),J=1,4)/0.96,1.83,1.08,3.00/,
     *    (PLANTN(4,J),J=1,4)/0.73,1.42,0.94,2.55/,
     *    (PLANTN(5,J),J=1,4)/0.50,1.01,0.80,2.10/,
     *    (PLANTN(6,J),J=1,4)/0.40,0.80,0.00,0.00/
      DATA (CHEW(1,J),J=1,4)/73.,73.,73.,72./,
     *     (CHEW(2,J),J=1,4)/78.,78.,78.,76./,
     *     (CHEW(3,J),J=1,4)/82.,82.,81.,81./,
     *     (CHEW(4,J),J=1,4)/84.,84.,83.,83./,
     *     (CHEW(5,J),J=1,4)/87.,87.,86.,87./,
     *     (CHEW(6,J),J=1,4)/89.,89.,0.,0./
      DATA(PREF(1,J),J=1,4)/3*.95,1.15/,
     *    (PREF(2,J),J=1,4)/3*.95,1.15/,
     *    (PREF(3,J),J=1,4)/3*.95,1.15/,
     *    (PREF(4,J),J=1,4)/3*.95,1.15/,
     *    (PREF(5,J),J=1,4)/3*.95,1.15/,
     *    (PREF(6,J),J=1,4)/1.,1.,0.,0./
      DATA(DMD(1,J),J=1,4)/.74,.74,.72,.76/,
     *    (DMD(2,J),J=1,4)/.68,.68,.66,.71/,
     *    (DMD(3,J),J=1,4)/.64,.64,.64,.66/,
     *    (DMD(4,J),J=1,4)/.61,.61,.61,.62/,
     *    (DMD(5,J),J=1,4)/.55,.55,.57,.58/,
     *    (DMD(6,J),J=1,4)/.50,.50,0.,0./
      CELECT(X,Y)=AMIN1(AMAX1(0.0,0.001*(X-Y)),0.95)
C
C   VARIABLE           MEANING
C
C     AMT        INTERMEDIATE VARIABLE
C    AVAILF      FACTOR WHICH LIMITS INTAKE IF AVAILABILITY IS LOW
C     CHEW       ESTIMATE OF THE FIBROUSNESS OR CHEWINESS OF FEED(BALCH(1971))
C     COMP       INTERMEDIATE VARIABLE
C    COMPON      INTERMEDIATE VARIABLE
C     DIET       INTERMEDIATE VARIABLE
C    DIETN       NITROGEN CONTENT OF SELECTED PASTURE
C    DIGEST      DIGESTIBILITY OF COMSUMED PASTURE
C     DMD        ARRAY HOLDING DRY MATTER DIGESTIBILITIES OF FRACTIONS
C     FACN       FACTOR BY WHICH N CONTENT OF I-TH SPP CAN INCR WITH N FERTILI
C    FACTOR      CHANGE IN N CONTENT OF PASTURE DUE TO LEVEL OF FERTAN(I)
C    FERTAN      ACTUAL N LEVEL OF SOIL
C    FIBRE       MEAN FIBROUSNESS OF WHOLE DIET
C      FN        THE MINIMUM OF FERTAN AND 1.0
C    FRACTN      FRACTION OF DIET NOT YET SATISFIED
C    FRCINT      FRACTION OF DIETERY INTAKE,INDEX CORRESPONDS TO DMD AND FC
C    PERCEN      FRACTION OF GROUND COVER OCCUPIED BY I-TH SPECIES IN J-TH PADI
C    PLANT       AMOUNT OF DRY MATTER IN I-TH COMPONENT,J-TH SPECIES IN K-TH P
C    PLANTN      ARRAY HOLDING THE N CONTENT OF THE I-TH COMPONENT, J-TH SPECI
C     PREF       RELATIVE PREFERENCE OF THE I-TH SPECIES
C    PTOTAL      TOTAL PASTURE DRYMATTER
C
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      PTOTAL(N)=0.0
      DIGEST(N)=0.0
      FIBRE (N)=0.0
      DO 30 I=1,6
      COMPON(I)=0.0
      DO 20 J=1,4
      AMT=PLANT(I,J,N)*PERCEN(J,N)
      PTOTAL(N)=PTOTAL(N)+AMT
      IF(PLANT(I,J,N).LT.BASE(I))AMT=0.0
      DIET(I,J)=PREF(I,J)*AMT
   20 COMPON(I)=COMPON(I)+DIET(I,J)
   30 CONTINUE
      FRACTN=1.0
      DO 50 I=1,6
      COMP(I)=FRACTN*CELECT(COMPON(I),BASE(I))
      FRACTN=FRACTN-COMP(I)
      DO 40 J=1,4
      IF(COMPON(I).LE..001)GOTO 35
      FRCINT(I,J)=COMP(I)*DIET(I,J)/COMPON(I)
      DIGEST(N)=DIGEST(N)+FRCINT(I,J)*DMD(I,J)
      FIBRE (N)=FIBRE (N)+FRCINT(I,J)*CHEW(I,J)
      GOTO 40
   35 FRCINT(I,J)=0.0
   40 CONTINUE
   50 CONTINUE
      AVAILF(N)=1.0-FRACTN
      IF(FRACTN.LT..001)GOTO 65
      DO 55 I=1,6
      DO 55 J=1,4
   55 FRCINT(I,J)=FRCINT(I,J)/AVAILF(N)
      FIBRE(N)=FIBRE(N)/AVAILF(N)
      DIGEST(N)=DIGEST(N)/AVAILF(N)
      AVAILF(N)=AMAX1(0.70,AVAILF(N))
   65 FN=AMIN1(1.0,FERTAN(N))
      DIETN(N)=0.0
      DO 10 J=1,4
      FACTOR=1.0+FN*FACN(J)
      DO 10 I=1,6
   10 DIETN(N)=DIETN(N)+FRCINT(I,J)*PLANTN(I,J)*FACTOR
      RETURN
C
C  A CALL IS MADE TO ANSUM2 AT THE COMMENCEMENT OF THE RUN IF A SUMMARY OF THE
C  SETINGS OF THE VARIBLES PLANTN,DMD,CHEW AND PREF IS REQUIRED
C
      ENTRY ANSUM2
      WRITE(1,80)
   80 FORMAT(*-  COMPONENT*, 9X,*CARPET GRASS*,21X,*PASPALUM*,25X,
     **KIKUYU*,21X,*WHITE CLOVER*/12X,4(3X,*DMD*,4X,*CHEW*,2X,*PREF*,
     *2X,*PLANTN*,3X))
      DO 100 I=1,6
      L=NAMEN(I)
      WRITE(1,90)L,(DMD(I,J),CHEW(I,J),PREF(I,J),PLANTN(I,J),J=1,4)
   90 FORMAT(3X,A8,1X,4(F6.2,F8.0,F6.2,F7.2,4X))
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MILK(I,N)
C
C  **  'MILK' ON ITS INITIAL CALL DETERMINES THE POTENTIAL MILK PRODUCTION
C      CURVE, ACCORDING TO LIVEWEIGHT. LATER CALLS DETERMINE THE POTENTIAL
C      MILK PRODUCTION FOR A PARTICULAR DAY FOR COWS IN CLASS-I, PADDOCK-N
C
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
C
C   VARIABLE        MEANING
C
C      AW       INTERMEDIATE VARIABLE
C     AWOOD     PARAMETER OF WOOD(1968) MILK PRODUCTION CURVE = WOOD'S A
C     BREED     A VARIABLE WHICH DETRMINES ABILITY TO PRODUCE MILK
C     BWOOD     EQUIVALENT TO B OF WOOD(1968) MILK PRODUCTION CURVE
C     CWOOD     EQUIVALENT TO C OF WOOD(1968) MILK PRODUCTION CURVE
C       N       PADDOCK IN WHICH COWS ARE PLACED
C     NDSUCK    NUMBER OF DAYS SINCE BIRTH OF CALVES
C     NOANIM    NUMBER OF ANIMALS IN THE I-TH CLASS, J-TH PADDOCK
C      POT      INTERMEDIATE VARIAGLE = POTYLD FOR(I-3)TH CLASS,J-TH PADDOCK
C     POTYLD    POT MILK PROD FOR CLASS 4 OR 5 IN J-TH PADDOCK
C      TMAX     DAY ON WHICH MAXIMUM YIELD OCCURS
C       WT      WEIGHT(KG) OF THE I-TH CLASS OF ANIMAL IN THE J-TH PADDOCK
C       X       INTERMEDIATE VARIABLE
C      YLDM     INTERMEDIATE VARIABLE
C     YLDMAX    MAXIMUM MILK YIELD THAT COULD BE OBTAINED
C
C  THE FOLLOWING SECTION OF THE SUBROUTINE IS ONLY ENTERED IN THE FIRST CALL
C  MILK FOR EACH LACTATION. THIS CALL SETS THE INITIAL VALUE OF AWOOD AND
C  DETERMINES THE YLDMAX VALUE FOR THAT LACTATION
C
      IF(NDSUCK(N).GT.0)GOTO 20
      IF(NOANIM(4,N).EQ.0)RETURN
      AW=1.-1.25*EXP(-.005365*WT(3,N))
      BREED=3.0
      BWOOD=.5
      AWOOD(1,N)=AW*BREED
      AWOOD(2,N)=AW*BREED
      CWOOD=.01
      TMAX=BWOOD/CWOOD
      YLDM=AW*(TMAX**BWOOD)*BREED
      YLDM=YLDM*EXP(-CWOOD*TMAX)
      YLDMAX(N)=YLDM
      RETURN
   20 X=NDSUCK(N)
      AW=AWOOD(I-3,N)
      POT=AW*(X**BWOOD)*EXP(-CWOOD*X)
      POTYLD(I-3,N)=POT
      RETURN
      END
```

These pages have been bound in the wrong place. They should come after page D 3 in the next appendix

SCREW

*** SCREW ***

A MODEL OF A BEEF ENTERPRISE OF UP TO 4 PADDOCKS
IN THE HIGH RAINFALL NORTH COAST OF NEW SOUTH WALES

S SIMULATION OF A
C CATTLE
R RAISING
E ENTERPRISE
W WITH A DIGITAL COMPUTER

MODEL WRITTEN BY H.JEFFERY
DIVISION OF PLANT INDUSTRY
C.S.I.R.O.
BOX 1600,P.O.
CANBERRA CITY
A.C.T.,2600

DATE 20/12/74
TIME 16.58

COMMENTS THIS RUN

THIS RUN DEMONSTRATES THE SUMMARISING FEATURES OF *SCREW* AND PROVIDES AN EXAMPLE OF THE CONSEQUENCES OF USING CATTLE OF DIFFERING MILK PRODUCING ABILITY, IN A WHOLE-FARM CONTEXT.

THE FIRST GRAPHS DEPICT THE CASE WHERE CATTLE OF HIGH MILK POTENTIAL ARE USED. MILK PRODUCTION IS GREATER, BUT SO IS COW LIVEWEIGHT LOSS AND THE PROBABILITY OF PREGNANCY. AN ADVANTAGE IS THAT THE CALVES HAVE A HIGHER WEANING WEIGHT,THE SECOND GRAPHS DEPICT THE CONSEQUENCES OF HAVING CATTLE OF LOW MILK PRODUCING ABILITY.

THE GRAPHING ROUTINES USED TO PRINT THESE GRAPHS ARE PART OF THE MODEL

*** * * PASTURE SUMMARY * * ***

SPECIES	TEMPERATURE FUNCTIONS COMMENCES	MAXIMIZES	FINISHES	CALCULATED CONSTANTS A1	B1	A2	B2
CARPET GRASS	12.	31.	37.	.1653	-3.5550	-.5236	5.2360
PASPALUM	10.	31.	37.	.1496	-3.0668	-.5236	5.2360
KIKUYU	8.	28.	34.	.1571	-2.8274	-.5236	3.6652
WHITE CLOVER	0.	25.	29.	.1257	-1.5708	-.7854	2.3562

INITIAL FERTILITY

PADDOCK	AREA (HA)	P FERTILITY (PPM)	N FERTILITY
1	100.	8	.40

PASTURE GROWTH AND COMPOSITION

SPECIES	VALUE OF RICHUD	MAX GROWTH RATE (KG/HA/DAY)	UPPER PARAMETER (KG/HA)	RATE CONSTANT	FRACTION OF UPPER PARAMETER AT WHICH MAX GROWTH OCCURS
CARPET GRASS	.50	100.	4500.	.044444	.25
PASPALUM	.50	200.	6250.	.064000	.25
KIKUYU	.50	250.	7500.	.066667	.25
WHITE CLOVER	.80	110.	4000.	.067139	.33

INITIAL AVAILABILITY

PADDOCK 1

COMPONENT	1	2	3	4	5	6	GRD COVER
CARPET GRASS	0	0	0	0	0	0	0.00
PASPALUM	0	0	0	0	0	0	0.00
KIKUYU	0	0	0	0	0	0	0.00
WHITE CLOVER	0	0	0	0	0	0	0.00

VALUES FOR FERTF FOR VARYING FN AND FP (PPM)

FN = NITROGEN STATUS (0-1 SCALE, ARBITRARY UNITS)
FP = PHOSPHOROUS STATUS (PPM AVAILABLE PHOSPHOROUS)

CARPET GRASS

FN / FP	.00	.25	.50	.75	1.0
0	.40	.49	.68	.85	.95
5	.41	.50	.70	.88	.98
10	.42	.51	.71	.89	.99
15	.42	.51	.71	.90	1.00
20	.42	.51	.71	.90	1.00

PASPALUM

FN / FP	.00	.25	.50	.75	1.0
0	.10	.14	.35	.70	.95
5	.11	.14	.36	.73	.98
10	.11	.14	.37	.74	.99
15	.11	.14	.37	.74	1.00
20	.11	.15	.37	.74	1.00

KIKUYU

FN / FP	.00	.25	.50	.75	1.0
0	.06	.07	.16	.49	.95
5	.06	.07	.17	.51	.98
10	.06	.07	.17	.52	.99
15	.06	.07	.17	.52	1.00
20	.06	.07	.17	.52	1.00

WHITE CLOVER

FN / FP	.00	.25	.50	.75	1.0
0	.23	.30	.32	.33	.33
5	.27	.34	.36	.37	.38
10	.40	.50	.54	.56	.56
15	.57	.73	.78	.81	.81
20	.70	.89	.96	.99	1.00

* * * SUMMARY OF ANIMAL DATA * * *

NO.	CLASS	PADDOCK 1 NO	PADDOCK 1 WEIGHT (KG)
1	STEERS	0	0
2	DRY COWS - EMPTY	0	0
3	DRY COWS - PREGNANT	0	0
4	LACTNG COWS - EMPTY	150	400
5	LACTNG COWS - PREGNT	0	0
6	UNWEANED CALVES	0	0
	TOTAL	150	

CONCEPTION RATES

LIVEWT CHANGE (KG/D)	NON LACTATING COWS LIVEWEIGHT(KG) 100	200	300	400	500	600
-1.0	.02	.02	.21	.49	.65	.69
-.5	.02	.02	.39	.66	.82	.87
0.0	.02	.17	.56	.84	.96	.96
.5	.02	.35	.74	.96	.96	.96
1.0	.02	.52	.92	.96	.96	.96

LIVEWT CHANGE (KG/D)	LACTATING COWS LIVEWEIGHT(KG) 100	200	300	400	500	600
-1.0	.02	.02	.04	.32	.48	.52
-.5	.02	.02	.22	.50	.66	.70
0.0	.02	.02	.40	.68	.84	.88
.5	.02	.18	.58	.86	.96	.96
1.0	.02	.36	.76	.96	.96	.96

COMPONENT	CARPET GRASS DMD	CHEW	PREF	PLANTN	PASPALUM DMD	CHEW	PREF	PLANTN	KIKUYU DMD	CHEW	PREF	PLANTN	WHITE CLOVER DMD	CHEW	PREF	PLANTN
LEAF 1	.74	73.	.95	1.42	.74	73.	.95	2.65	.72	73.	.95	1.36	.76	72.	1.15	3.90
LEAF 2	.68	78.	.95	1.19	.68	78.	.95	2.24	.66	78.	.95	1.22	.71	76.	1.15	3.45
LEAF 3	.64	82.	.95	.96	.64	82.	.95	1.83	.64	81.	.95	1.08	.66	81.	1.15	3.00
LEAF 4	.61	84.	.95	.73	.61	84.	.95	1.42	.61	83.	.95	.94	.62	83.	1.15	2.55
DRY	.55	87.	.95	.50	.55	87.	.95	1.01	.57	86.	.95	.80	.58	87.	1.15	2.10
INFLORES	.50	89.	1.00	.40	.50	89.	1.00	.80	0.00	0.	0.00	0.00	0.00	0.	0.00	0.00

INITIAL CONDITIONS AND PARAMETER SETTINGS

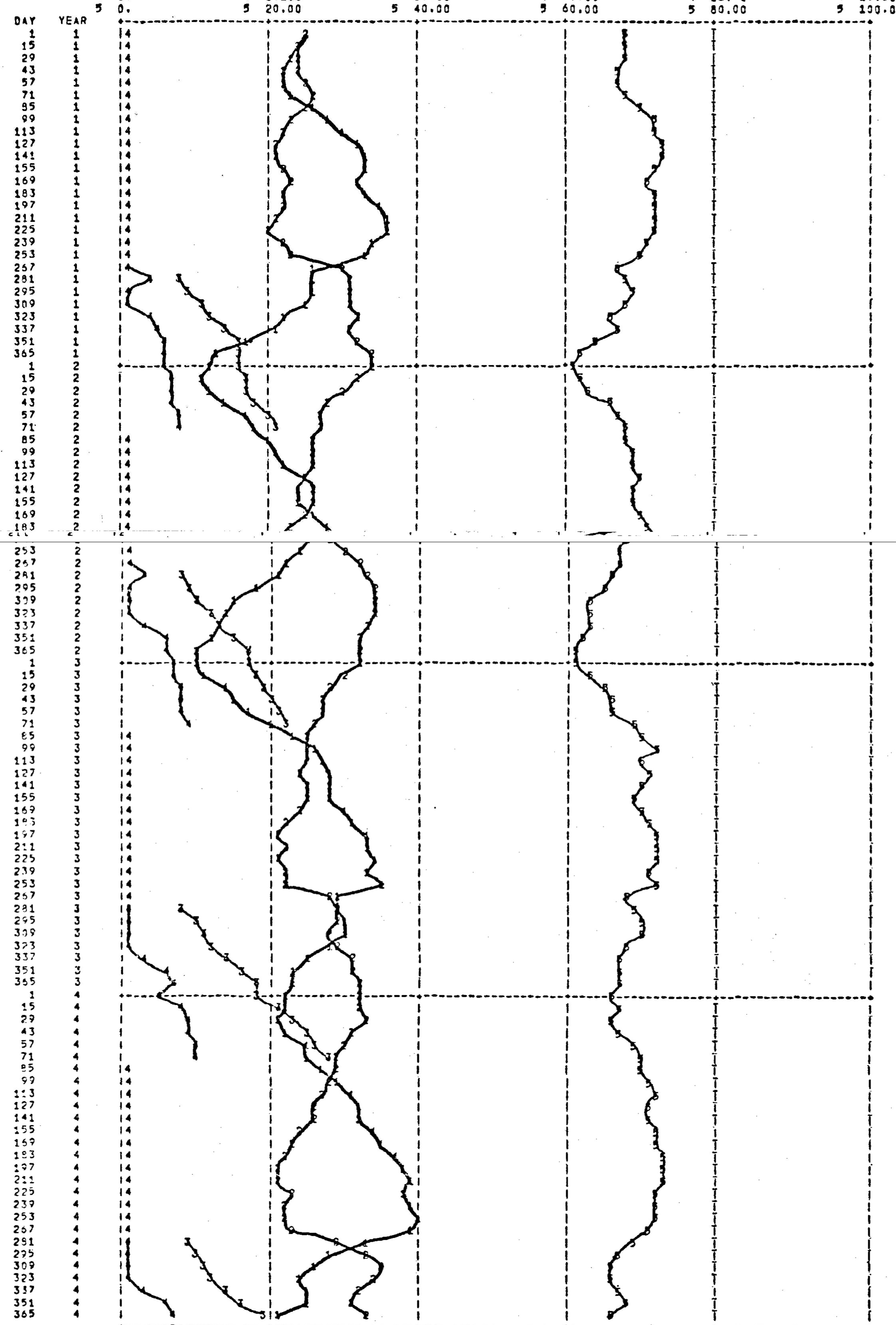
INITIAL TEMPERATURE 20.0 DEG. C
PARAMETER PENMAN IS SET AT .70

SOIL PARAMETERS

	HORIZON 1		HORIZON 2		
DEPTH (MM)	250.		500.		
WILTING POINT	.15		.20		
FIELD CAPACITY	.35		.30		
FIELD STORAGE	.40		.35		
INITIAL SOIL MOISTURE	.35		.30		
STORAGE AT FLD CAP (MM)	50.	+	50.	=	100.
STORAGE AT FLD SAT (MM)	63.	+	75.	=	138.
WILTING POINT (MM)	38.	+	100.	=	138.
FIELD CAPACITY (MM)	88.	+	150.	=	238.

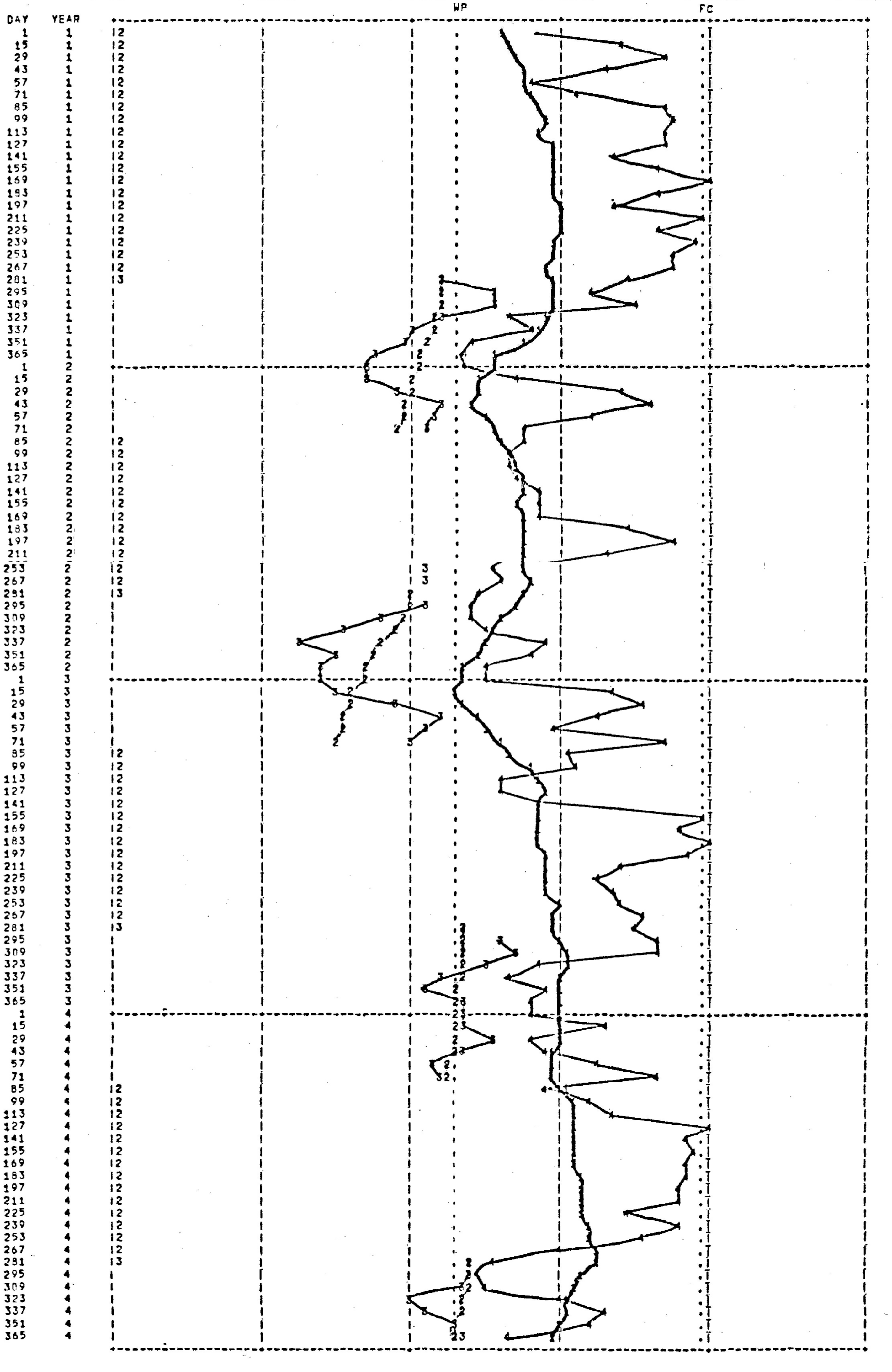
PADDOCK	GRAPH	VARIABLE	GRAPH	VARIABLE
1	1	GREEN LEAF DRY MATTER (KG/HA)	2	DRY AND DEAD DRY MATTER (KG/HA)
	3	WEIGHT OF CALVES (KG)	4	PASTURE INTAKE OF CALVES (KG/DAY)
	5	DIGESTIBILITY OF CONSUMED PASTURE		

PLOT	SCALE	PLOT	SCALE	PLOT	SCALE	PLOT	SCALE	PLOT	SCALE	PLOT	SCALE
1	0.	1	1600.	1	3200.	1	4800.	1	6400.	1	8000.
2	0.	2	1600.	2	3200.	2	4800.	2	6400.	2	8000.
3	0.	3	80.00	3	160.0	3	240.0	3	320.0	3	400.0
4	0.	4	3.200	4	6.400	4	9.600	4	12.80	4	16.00
5	0.	5	20.00	5	40.00	5	60.00	5	80.00	5	100.0

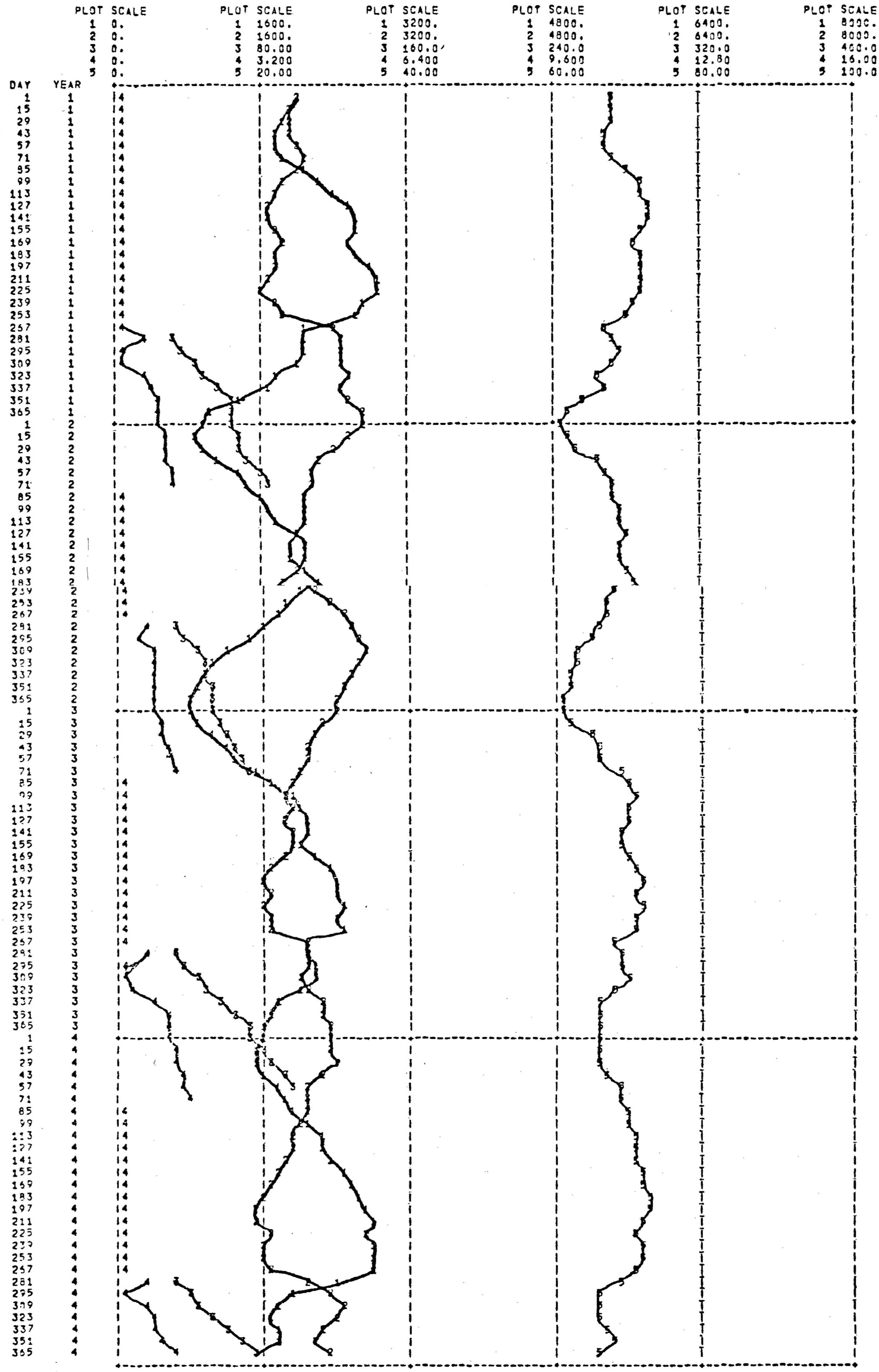


PADDOCK	GRAPH	VARIABLE	GRAPH	VARIABLE
1	1	TOTAL PASTURE DRY MATTER (KG/HA)	2	WEIGHT OF LACTATING EMPTY COWS (KG)
	3	14-DAY AV WT CHANGE LAC EMPTY COW (KG/D)	4	14-DAY MOVING AVERAGE OF SOIL MOIST (MM)

PLOT SCALE	PLOT SCALE	PLOT SCALE	PLOT SCALE	PLOT SCALE	PLOT SCALE
1 0.	1 1600.	1 3200.	1 4800.	1 6400.	1 8000.
2 0.	2 200.0	2 400.0	2 600.0	2 800.0	2 1000.
3 -2.000	3 -1.200	3 -.4000	3 .4000	3 1.200	3 2.000
4 0.	4 60.00	4 120.0	4 180.0	4 240.0	4 300.0

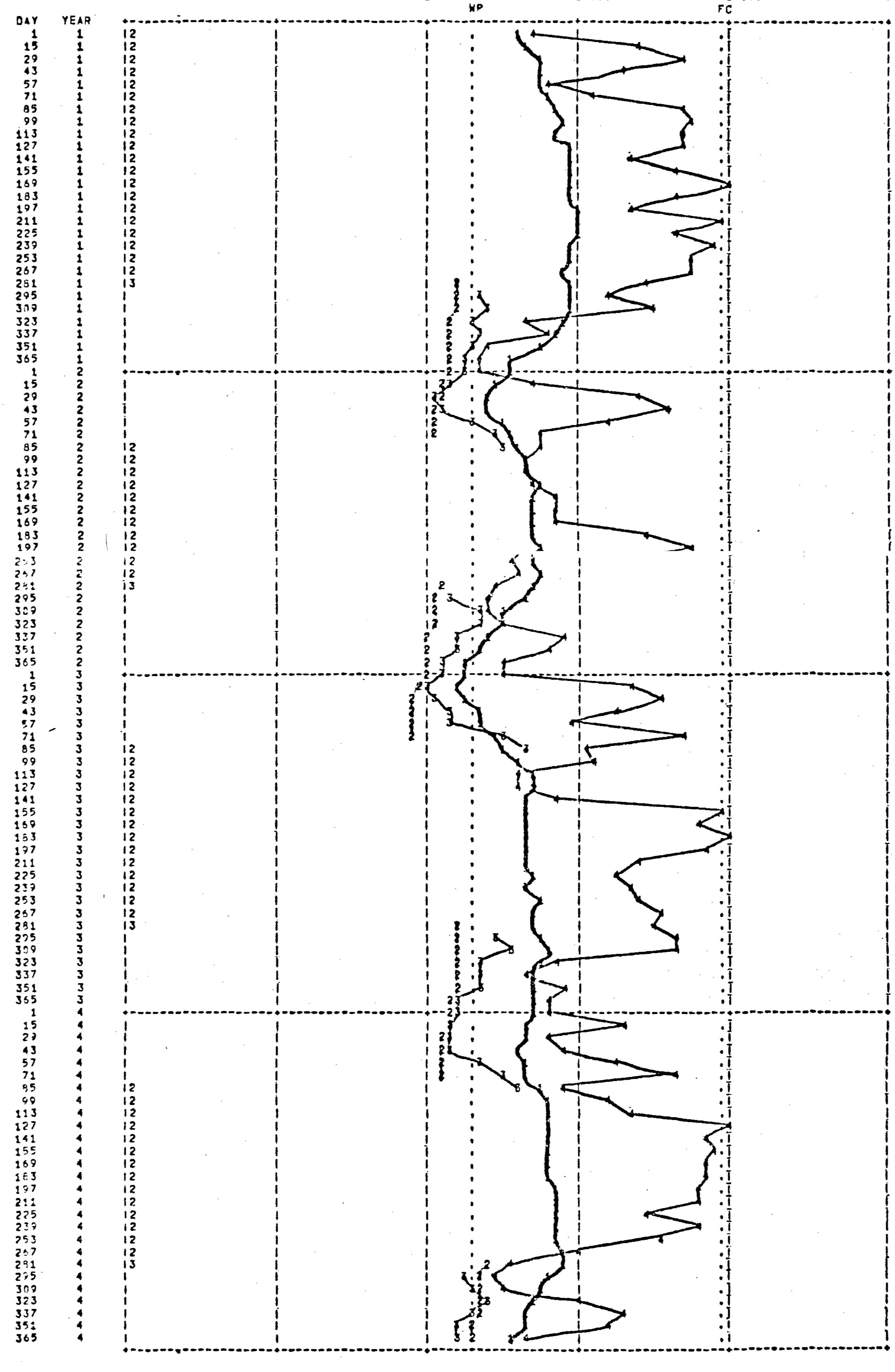


PADDOCK	GRAPH	VARIABLE	GRAPH	VARIABLE
1	1	GREEN LEAF DRY MATTER (KG/HA)	2	DRY AND DEAD DRY MATTER (KG/HA)
	3	WEIGHT OF CALVES (KG)	4	PASTURE INTAKE OF CALVES (KG/DAY)
	5	DIGESTIBILITY OF CONSUMED PASTURE		



PADDOCK	GRAPH	VARIABLE	GRAPH	VARIABLE
1	1	TOTAL PASTURE DRY MATTER (KG/HA)	2	WEIGHT OF LACTATING EMPTY COWS (KG)
	3	14-DAY AV WT CHANGE LAC EMPTY COW (KG/D)	4	14-DAY MOVING AVERAGE OF SOIL MOIST (MM)

PLOT SCALE	PLOT SCALE	PLOT SCALE	PLOT SCALE	PLOT SCALE	PLOT SCALE
1 0.	1 1600.	1 3200.	1 4800.	1 6400.	1 8000.
2 0.	2 200.0	2 400.0	2 600.0	2 800.0	2 1000.
3 -2.000	3 -1.200	3 -.4000	3 .4000	3 1.200	3 2.000
4 0.	4 60.00	4 120.0	4 180.0	4 240.0	4 300.0



Appendix D

A Sample of the Model Output

In this appendix a sample of the output obtained from the model is presented. Two aspects of the output are demonstrated: (i) the optional summary that can be put at the commencement of each run and (ii) the plotting routine that was developed as part of the model.

A comparison was made between the use of cows with high (ex-dairy stock) and low (beef cattle) milk production potentials, run as a breeding unit. The ex-dairy cows had the potential to produce twice as much milk as the other group. The increased milk yield was expected to produce a greater calf growth rate. An expected disadvantage was that because these cows produced more milk, their liveweights would be lower. Consequently, a lower probability of pregnancy would result. In a good season this would not be a major problem as the cows could manage a high milk yield and some liveweight gain. However, in a poor season the consequences could be severe. Whether it is an advantage, or otherwise, to have cows with a high milk production potential depends largely on the rainfall received in the present season but is also influenced by the effect of previous seasons on cattle performance.

The comparison presented here is a further example of the use to which simulation model, such as SCREW, may be put. The answers that are obtained from this sort of simulation run may be of direct relevance to questions of how quickly, if at all, a farmer should change from ex-dairy to beef cattle. A fairly high stocking rate (1.5 breeding cows ha^{-1}) was employed in this comparison. When there were periods of low rainfall, the resultant low soil moisture levels caused low evaporation ratios and these, in turn, raised the senescence rate. Consequently, much of the feed that was on offer was of low quality and cattle lost weight. At times this loss was sufficient to cause a number of "deaths".

An initial comparison of systems incorporating either ex-dairy or beef cattle clearly demonstrated an inadequacy in the animal sub-model. The model, as described in Chapter 4, caused a cow's intake to be increased if it was lactating. The extent of the increase varied, depending on the cow's milk potential for the day (POTYLD, kg) and the cow's maximum daily potential yield for the entire lactation (YLDMAX, kg). The intake of lactating cows was increased by the fractional amount 0.4*POTYLD/YLDMAX. The following table which lists the intakes of a hypothetical feed, is shown to demonstrate this effect. The first entry in the table is a "reference" value to indicate the intake of a dry, non-pregnant cow.

Potential daily yield (kg)	YLDMAX (kg)	Intake (kg)
Dry, non-pregnant cow		7.0
5.0	10.0	8.4
10.0	10.0	9.8
10.0	20.0	8.4
20.0	20.0	9.8
5.0	30.0	7.5
10.0	30.0	7.9
20.0	30.0	8.9
30.0	30.0	9.8

Although the consumption of a cow with a POTYLD of 10kg could be expected to be at least as great as that of a cow whose POTYLD is 5kg, this was not always the case, e.g. compare the second entry and the third last entry. Obviously, the way the model was structured would bias the output against cows with a high YLDMAX (i.e. dairy cows). A more realistic structure would be to have the fractional increase in intake as a function of POTYLD only.

This deficiency in the model would probably not have been very important in the system test described in Chapter 6 because only one type of cow(beef) was being considered in that test. However, it was important in the comparison of ex-dairy and beef herds, and consequently an alteration was made to the model in an attempt to correct it: beef cattle had their intake raised by 0.31*POTYLD/YLDMAX, whilst the increase given to the ex-dairy stock was 0.4*POTYLD/YLDMAX. Unfortunately, the changes improved, but did not correct, the shortcoming. Nonetheless, the results are presented in order to demonstrate the general features of the model's behaviour, but little attention should be given to the actual values obtained.

The first two graphs were obtained from the "ex-dairy system" and the last two from the "beef system". The dotted lines, in the graphs in which the moving average of soil moisture has been plotted, represent field capacity and wilting point. These levels are indicated by "FC" and "WP" respectively on the ordinate axis. Simulated mating occurred on day 1 (Jan 1), hence calving resulted on day 280. Calves were weaned on day 80, 165 days after calving. The output obtained from the model follows.

A summary of the results of this run are shown in the following table.

	Year 1	Year 2	Year 3	Year 4
Ex-dairy cows				
No. cows on Jan 1	150	126	71	70
No. calves born	133	77	58	55
Calf weight at wean (kg)	99	90	118	74*
Total weight of calves (kg)	13167	6930	6844	4070
Beef cows				
No. cows on Jan 1	150	137	120	120
No. calves born	143	107	96	86
Calf weight at wean (kg)	86	74	106	78*
Total weight of calves (kg)	12298	7918	10176	6708

* simulation stopped on day 365, hence these values are for 2 month old calves.

If the milk production and feed utilization routines had been restructured so that the increase in intake as a result of lactation was a function of the potential milk yield, rather than the POTYLD/YLDMAX ratio, then a more reasonable output would have been obtained. As it was, the ex-dairy cows produced more milk, but their intakes were often so low that considerable liveweight losses resulted. Consequently, too many of these cows succumbed to the mortality function.

Nonetheless, the output is useful for demonstrating the consequences of carrying different stock. In year 1, the ex-dairy stock, despite lower calf numbers, produced the greater amount of total calf liveweight gain. Soil moisture levels were very much lower in the second and third years - it was in these years that the "penalty" for using ex-dairy cows was greatest. On a number of occasions the 14-day average liveweight change of the ex-dairy cows dropped below -.4 kg d^{-1}; this was the lowest value graphed for the beef cattle.

Despite the larger liveweight loss from the ex-dairy ›ws, the extra milk production from them grew the heaviest ılves in all years except the final year. In the last year ıe difference between the liveweights of the calves was ıight but in favour of the beef cattle. This may have :curred for several reasons: (i) at the fourth calving the c-dairy cows were lighter (486 vs 531kg) and as the ›tential milk production curve is, in part, a function of ›ight (Chapter 4), the difference in potential milk roduction between the groups would not have been as great, ii) during the lactation, the higher liveweight of the beef ıttle resulted in a higher intake and thus the 31% maximum ıcrease in intake of the beef cows may not have been, in bsolute terms, very different from the 40% maximum increase f the ex-dairy stock and (iii) the higher grazing pressure n the beef cow paddocks caused a greater utilization of asture and a higher content of the more digestible and referred clover.

Probably little would have been gained had this run not ttempted to compare cattle as divergent as beef and dairy attle. If the comparison had been between say, a slow and fast growing beef breed, then the inadequacy of the milk roduction routine might not have been detected. It may be seful to test all new models with the extremes of potential ystems to see if any latent shortcomings become evident.

```
      PROGRAM BOSS(INPUT,OUTPUT,PL1,PL2,PL3,PL4,PL5,
     *           TAPE60=INPUT,TAPE1=OUTPUT,
     *           TAPE11=PL1,TAPE12=PL2,TAPE13=PL3,TAPE14=PL4,
     *          TAPE15=PL5)
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      COMMON /PLOT/NUMPLT(6),NPLOTT(60),AVPGRO(4,4),AVEVAC,AVEVPT,
     *            AVEVRT,AVSAVE(8,4,14),INTPLT,AVSM
      DIMENSION NDY(12),PLANSV(6,4,4),PERSV(4,4)
      DIMENSION KRITD(12),SUPER(11),AMMON(11),MMDAY(16),PASDM(15),
     *    PERG(15),BOTCMP(4,15),WTMEAR(15),PASNIP(4),OBJFN(4),DIFF(7)
     *    ,WTOF(4),RESTOK(4),PASN(4),BIAS(7)
      DIMENSION NSPACE(15),NDAYY(15),NZP(11),NZQ(11),NBLK(11),SV(8,15)
      DATA NSPACE/1,3,5,2,6,4,3,6,4,4,5,4,5,3,5/
      DATA NDAYY/167,201,247,274,331,4,35,91,130,172,217,257,308,340,24/
      DATA NZQ/11*10H----------/,NZP/5(10HI         ,10H          ),
     *     10HI         /
      DATA                 NDY/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA WTOF/2.0E-7,30.0,10.0,0.0002/,RESTOK/196.,180.,183.,177./
```

THIS IS AN EXAMPLE OF ONE DECK OF THE MAIN CALLING PROGRAM THAT WAS USED
THIS DECK MAY NOT EVEN WORK WITH THE REMAINDER OF THE PROGRAM AS
SUBROUTINE CLISIM WAS ALTERED IN THIS RUN SO THAT DATA COULD BE READ IN,
RATHER THAN GENERATED. IN ALL OTHER RESPECTS IT SHOULD HOWEVER WORK

GOOD-LUCK IF YOU TRY TO USE IT

VARIABLE	MEANING
AREA	AREA OF EACH PADDOCK
FC	FIELD CAPACITY OF SOIL LAYERS (FRACTION)
FERTAN	ACTUAL N FERTILITY OF SOIL
FERTAP	ACTUAL P FERTILITY OF SOIL
FERTN	INITIAL N FERTILITY
FERTP	INITIAL P FERTILITY
FS	FIELD SATURATION (FRACTION)
GRAIN	AMT GRAIN FED TO I-TH PADDOCK
HAY	AMT HAY FED TO I-TH PADDOCK
HORIZD	DEPTH (CM) OF SOIL LAYERS
INTPLT	INTERVAL (DAYS) BETWEEN PLOTTING OUTPUTS
KDAY	DAY OF MONTH
KMONTH	MONTH OF YEAR
KPREV	=0 IMPLIES NO RAIN THAT DAY; =1 IMPLIES RAIN
KYEAR	YEAR OF THAT RUN
LDAY	DAY OF YEAR. JAN 1=1, JAN 2=2,ETC.
MONTH	ARRAY HOLDING MONTHS IN HOLLERITH CHARACTERS
NDAY	NO. DAYS IN MONTH
NDPREG	NUMBER OF DAYS COWS IN I-TH PADDOCK HAVE BEEN PREGNANT
NDSUCK	NUMBER OF DAYS SINCE BIRTH OF CALVES IN I-TH PADDOCK
NDY	ARRAY HOLDING NO. DAYS IN EACH MONTH

```
  NMONTH    NO, MONTHS FOR THIS RUN
  NOANIM    NUMBER OF ANIMALS IN I-TH CLASS, J-TH PADDOCK
   NPAD     PADDOCK NUMBER
  NPADOK    NO, PADDOCKS ON THIS RUN, MUST BE LESS THAN 5
  NPRSUM    =0,PREVENTS ANY PRINTOUT OF SUMMARIES; =1 ALLOWS PRINTOUT
  NSEED1    SEEDS FOR RANDOM NUMBER GENERATION. SETTING NSEED1 DEFINES RAIN
  NSEED2    SEED VALUE DEFINES RANDOM NO, SEQUENCE OTHER THAN IN CLISIM
   NSUM     NO OF DAYS(INCL ALL FOR CURRENT MONTH)GONE SO FAR THAT YEAR
   NYEAR    NO YEARS RUN REQUIRED TO GO FOR
  PASMAX    CEILING YIELDS FOR PASTURE SPECIES
  PENMAN    PARAMETER IN RANGE (.6,.8) DEFINING EVPOT FROM PAN EVAPORATION
  PERCEN    FRACTION OF GROUND COVER OCCUPIED BY I-TH SPECIES IN J-TH PADDOCK
  PGREEN    AMOUNT OF GREEN PASTURE, USED ONLY FOR OUTPUT PURPOSES
  PGROTH    PASTURE GROWTH RATES
  PLANT     AMOUNT OF DRY MATTER IN I-TH COMPONENT,J-TH SPECIES IN K-TH PADDK
  PMAXGR    MAXIMUM GROWTH RATE OF THE I-TH PASTURE SPECIES
  PTOTAL    TOTAL PASTURE DRYMATTER
  RICHUD    PARAMETER OF GROWTH EQUATION, EQUIVALENT TO M PARAMETER,RICHARDS
    SM      SOIL MOISTURE(FRACTION) IN THE I-TH SOIL LEVEL
  SUMMON    MONTHLY AVERAGES OF SEVERAL CLIMATIC VARIABLES
   SUMYR    YEARLY AVERAGES OF SEVERAL CLIMATIC VARIABLES
  TEMFAC    CONSTANTS DEFINE RESPONSE CURVE OF PLANT TO TEMPERATURE
   TEMP     TEMPERATURE
   TOTSM    TOTAL SOIL MOISTURE
   TRMAX    MAXIMUM TRANSPIRATION RATES OF SOIL LAYERS
    WP      WILTING POINT(FRACTION) OF SOIL LAYERS
    WT      WEIGHT(KG) OF THE I-TH CLASS OF ANIMAL IN THE J-TH PADDOCK
    Z       DAY OF YEAR * 2 * PI / 365, USED IN SINE FUNCTIONS


**  THE PURPOSE OF THIS ROUTINE IS TO CONTROL THE WHOLE MODEL.
    'BOSS' CALLS ALL SUBROUTINES AND ORGANISES THE WHOLE MODEL. ANY
    MANAGEMENT STRATEGIES WILL BE INCORPORATED INTO 'BOSS'

FP AND FN CAN ONLY COVER A RANGE OF FROM 0 TO 1. THIS APPROACH WAS CHOSEN TO
SPECIFY PHOSPHOROUS AND NITROGEN FERTILITY OF THE SOIL, RATHER THAN DEFINING
IT IN TERMS OF CONCENTRATION OF P AND N IN THE SOIL AS IT IS POSSIBLY A MORE
GENERAL APPROACH AND AVOIDS THE STRICT DEFINITION OF SOIL LEVELS ONE IS
DEALING WITH WHEN DEFINING P AND N CONCENTRATION. THIS IS PARICULARLY
RELEVANT WHERE P AND N CONCENTRATION IS POORLY CORRELATED WITH TRUE P AND N
STATUS OF THE SOIL, AND HENCE WHERE A STRICT DEFINITION OF CONCENTRATION
WOULD SEEM TO BE INAPPROPRIATE., APPROXIMATE CONVERSIONS FOLLOW IN WHICH
THE CONCENTRATION OF P AND N IN THE FIRST 8 CM OF THE SOIL ARE DEFINED
        P(%)=.15+FP*.35
        N(%)=.20+FN*.40

   INTPLT=10
   KPREV=0
   MOVEIN=0
   NPADOK=1
   NPRSUM=0
   NRITE=0
   NSEED1=2000
   NSEED2=1000
   NSET=4
   PENMAN=.8
   READ(60,10)(WP(I),FC(I),FS(I),SM(I),HORIZD(I),TRMAX(I),I=1,2)
10 FORMAT(6F5.2)
   READ(60,20)(PASMAX(I),I=1,4),(PMAXGR(I),I=1,4)
20 FORMAT(4F5.0)
   DO 40 I=1,4
   READ(60,30)(TEMFAC(I,J),J=1,3)
```

```
 30 FORMAT(3F5,0)
 40 CONTINUE
    READ(60,50)(FERTP(I),I=1,NPADOK)
    READ(60,50)(FERTN(I),I=1,NPADOK)
 50 FORMAT(4F5.2)
    DO 60 I=1,NPADOK
    FERTAP(I)=FERTP(I)
    FERTAN(I)=FERTN(I)
    NDSUCK(I)=0
    CALL MILK(1,I)
    NDSUCK(I)=1
    CALL MILK(4,I)
    NDPREG(I)=0
    GRAIN(I)=0.0
    HAY(I)=0.0
 60 CONTINUE
    DO 65 I=1,4
    CALL FERTZ(I,1)
    CALL SINSOL(I)
    RICHUD(I)=1.1
******   NOT SURE WHETHER THESE WERE THE VALUES LAST USED
 65 CONTINUE
    RICHUD(4)=1.5
    FN=FERTN(1)
    FP=FERTP(1)
    CALL RECORD
    CALL PARSET
    NPRSUM=1
    CALL PASUM
    NPRSUM=0
    CALL ANSUM
    CALL SUBREC
    KRITD(12)=-100
    MMDAY(16)=-100
    T11=0.
    WRITE(11,706)
706 FORMAT(///10H**********,*SUMMARY OF OBJFNS*//* FUNCTION  VALUE*/)
    DO 600 NST=1,NSET
    FERTAN(1)=FERTN(1)
    FERTAP(1)=FERTP(1)
    IF(NST,GT.2)FERTAN(1)=0.75
    WRITE(12,801)
    WRITE(13,801)
801 FORMAT(1HQ)
    SM(1)=0.30
    SM(2)=0.30
    TOTSM=200.0
    NPRNT=0
    DO 102 I=1,6
    BIAS(I)=0.
    WTMAX(I,J)=0.0
102 CONTINUE
    BIAS(7)=0.
    DO 85 I=1,6
    DO 83 J=1,12
 83 SUMMON(I,J)=0.0
 85 SUMYR(I)=0.0
    READ(60,11)ICELL,IBLK,STOCKR,DESCA,DESCB
    NOANIM(1,1)=2
    NOANIM(2,1)=1
    WRITE(12,802)DESCA,DESCB,(K,K=100,400,60),NZP,NZQ
802 FORMAT(///20X,*COMPARISION OF LIVEWEIGHTS FROM MEARS 1973(A) AND*,
```

```
  1  * MODEL(1)*/40X,*TREATMENT *,2A10//15X,6(I3,17X)/16X,11A10/
  2   9X,*DAY*,4X,10A10,A1)
     WRITE(13,803)DESCA,DESCB,(K,K=25,125,25),(K,K=2,8,2),NZP,NZQ
 803 FORMAT(///20X,*COMPARISION OF TOTAL DRY MATTER AND PERCENT GREEN F
    1ROM MEARS 1973(A,B) AND MODEL(1,2)*/40X,*TREATMENT *,2A10//
  2  16X,*0   *,5(I18,*00*)/16X,*0 *,4(18X,1H ,I1),17X,4H1,0 /
  3      16X,11A10/9X,*DAY*,4X,10A10,A1)
     AREA(1)=3.0/STOCKR
  11 FORMAT(2I5,F5.1,35X,2A10)
     WRITE(1,21)DESCA,DESCB,STOCKR,ICELL,IBLK
     WRITE(1,1111)NPRNT
     NPRNT=5
  21 FORMAT(1H1/20X,*DESCRIPTION     STOCKING     PADDOCK  BLOCK*/
   *     37X,*RATE*/21X,A10,A5,F5.1,I10,I8/)
     READ(60,31)(KRITD(J),SUPER(J),AMMON(J),J=1,11)
  31 FORMAT(6X,4(I3,2F3.0,1X)//6X,7(I3,2F3.0,1X))
     DO 51 J=1,15
  51 READ(60,41)MMDAY(J),PASDM(J),WTMEAR(J),PERG(J),(BOTCMP(I,J),I=1,4)
  41 FORMAT(5X,I5,12X,2F5.0,5X,5F5.2)
     PGR=PASDM(1)*PERG(1)
     PDR=PASDM(1)-PGR
     DO 92 I=1,4
     DO 91 J=1,4
  91 PLANT(J,I,1)=PGR*0.25
     PLANT(5,I,1)=PDR
  92 PERCEN(I,1)=BOTCMP(I,1)
     WT(1,1)=WTMEAR(1)
     WT(2,1)=WTMEAR(1)
     NS=(NSET-NST)*19
     IF(NS.EQ.0)GOTO 55
     DO 52 I=1,NS
  52 READ(60,53)A
  53 FORMAT(A10)
  55 IND=1
     PTOTAL(1)=PASDM(1)
     KRITF=2
     KRITM=1
     LBACK=0
     LDAY=167
     DO 54 I=1,4
     PLANT(6,I,1)=0.0
  54 OBJFN(I)=0.0
 115 Z=LDAY*2.0*3.14159/365.
     TSM=0.
     SGTOT=0.
 100 CALL CLISIM(LBACK,IND)
     IF(LDAY.NE.56)GOTO 111
     WT(1,1)=RESTOK(NST)
     WT(2,1)=RESTOK(NST)
     WRITE(1,109)
 109 FORMAT(    //* COMMENCEMENT OF SECOND YEAR OF TRIAL*//)
     NPRNT=NPRNT+5
 111 CALL PASTYA
     CALL COMPET
     CALL EATUP
     TSM=TSM+1.0
     SGTOT=SGTOT+TOTSM
     MOVEIN=MOVEIN+1
     IF(MOVEIN.EQ.15)MOVEIN=1
     CALL MOVEAV(MOVEIN)
     IF(LDAY/INTPLT.EQ.(LDAY+1)/INTPLT)GOTO 605
     NPRNT=NPRNT+1
```

```
      DO 117 I=1,4
  117 PASNIP(I)=0.
      PAST=0,
      DO 118 I=1,4
      DO 119 J=1,6
  119 PASNIP(I)=PASNIP(I)+PERCEN(I,1)*PLANT(J,I,1)
  118 PAST=PAST+PASNIP(I)
      DO 123 I=1,4
  123 PASN(I)=PASNIP(I)/PAST
      PDR=0.
      DO 127 I=1,4
  127 PDR=PDR+PERCEN(I,1)*(PLANT(5,I,1)+PLANT(6,I,1))
      PAST=PAST-PDR
      WTT=(WT(1,1)*2.0+WT(2,1))/3.0
      CWL=(WTGAIN(1,1)*2.0+WTGAIN(2,1))/3.0
      TKE=(PASINT(1,1)*2.0+PASINT(2,1))/3.0
      WRITE(1,1112)LDAY,PAST,PDR,PTOTAL(1),(PGROTH(K,1),K=1,4),
     * (PASN(K),K=1,4),TKE,TEMP,RAIN,SENESC,SENEST,DECAY,WTT,CWL,
     *     TOTSM,DIGEST(1),DIETN(1),FIBRE(1),RATIO
      IF(NPRNT.LT.56)GOTO 605
      NPRNT=1
      WRITE(1,1111)NPRNT
  605 IF(LBACK.LT.0)GOTO 700
      IF(KRITD(KRITF).NE.LDAY)GOTO 610
      CALL FTLIZE(1,0,SUPER(KRITF))
      CALL FTLIZE(1,1,AMMON(KRITF))
      NPRNT=NPRNT+2
      KRITF=KRITF+1
  610 IF(MMDAY(KRITM).NE.LDAY)GOTO 100
      PASTL=0.0
      PASG=0,0
      DO 620 I=1,4
      PASNIP(I)=0.0
  620 CONTINUE
      DO 640 I=1,4
      DO 630 J=1,6
      IF(J.LE.4)PASG=PASG+PERCEN(I,1)*PLANT(J,I,1)
  630 PASNIP(I)=PASNIP(I)+PERCEN(I,1)*PLANT(J,I,1)
  640 PASTL=PASTL+PASNIP(I)
      PASG=PASG/PASTL
      DIFF(1)=PASDM(KRITM)-PTOTAL(1)
      DIFF(2)=PERG(KRITM)-PASG
      DO 650 I=1,4
      PASN(I)=PASNIP(I)/PASTL
  650 DIFF(I+2)=BOTCMP(I,KRITM)-PASN(I)
      WTT=(WT(1,1)*2.0+WT(2,1))/3.0
      DIFF(7)=WTMEAR(KRITM)-WTT
      DO 660 I=3,6
  660 OBJFN(3)=OBJFN(3)+DIFF(I)**2*WTOF(3)
      OBJFN(1)=OBJFN(1)+DIFF(1)**2*WTOF(1)
      OBJFN(2)=OBJFN(2)+DIFF(2)**2*WTOF(2)
      OBJFN(4)=OBJFN(4)+DIFF(7)**2*WTOF(4)
      WTOBFN=OBJFN(1)+OBJFN(2)+OBJFN(3)+OBJFN(4)
      SGTOT=SGTOT/TSM
      NPOST=(SGTOT-137,5)/(237,5-SGTOT)*10,0+0,5
      SGTOT=0.
      TSM=0,
      NPOST=80+MAX0(1,MIN0(10,NPOST))
      DO 809 NPARM=1,2
      DO 804 I=1,11
  804 NBLK(I)=NZP(I)
      CALL  STCH(NBLK,NPOST,1RS)
```

```
      IF(NPARM.EQ.2)GOTO 806
      SV(1,KRITM)=WTT
      NPOS=(WTT-100.)/3.+0.5
      NPOS=MAX0(1,MIN0(101,NPOS))
      CALL STCH(NBLK,NPOS,1R1)
      NPOS=(WTMEAR(KRITM)-100.)/3.0+0.5
      NPOS=MAX0(1,MIN0(101,NPOS))
      CALL STCH(NBLK,NPOS,1RA)
  805 FORMAT(16X,10A10,A1)
      NTTT=NSPACE(KRITM)
      GOTO 808
  806 NPOS=PTOTAL(1)/125.0+0.5
      NPOS=MAX0(1,MIN0(101,NPOS))
      CALL STCH(NBLK,NPOS,1R1)
      SV(2,KRITM)=PTOTAL(1)
      NPOS=PASDM(KRITM)/125.0+0.5
      NPOS=MAX0(1,MIN0(101,NPOS))
      CALL STCH(NBLK,NPOS,1RA)
      NPOS=PASG*100.0+0.5
      NPOS=MAX0(1,MIN0(101,NPOS))
      CALL STCH(NBLK,NPOS,1R2)
      SV(3,KRITM)=PASG
      NPOS=PERG(KRITM)*100.+0.5
      NPOS=MAX0(1,MIN0(101,NPOS))
      CALL STCH(NBLK,NPOS,1RB)
  808 LP=11+NPARM
      DO 807 I=1,NTTT
      IF(I.EQ.2.AND.KRITM.EQ.8)GOTO 831
      WRITE(LP,805)NZP
      GOTO 807
  831 WRITE(LP,805)NZQ
  807 CONTINUE
      WRITE(LP,810)NDAYY(KRITM),NBLK
  810 FORMAT(I12,4X,10A10,A1)
  809 CONTINUE
      DO 811 I=1,4
  811 SV(I+3,KRITM)=PASN(I)
      SV(8,KRITM)=WTOBFN
      DO 836 J=1,7
  836 BIAS(J)=BIAS(J)+DIFF(J)/15.0
      IF(NRITE.EQ.0)GOTO 695
  665 WRITE(11,680)LDAY,PASDM(KRITM),PAST_     ,DIFF(1),OBJFN(1),
     *                  PERG(KRITM),PASG,DIFF(2),OBJFN(2)
  680 FORMAT(/30X,*COMPARISION ON DAY*,I4/
     *        20X,*ATTRIBUTE              MEARS         MODEL       DIFF      OBJFN*/
     *     15X,*TOTAL PASTURE DM*,F8.0,F11.0,F9.0,G12.3/
     *     15X,*FRACTION GREEN*, F12.2,F11.2,F9.2,G10.3)
      WRITE(11,690)(I,BOTCMP(I,KRITM),PASN(I),DIFF(I+2),I=1,4),
     *                  OBJFN(3),WTMEAR(KRITM),WTT,DIFF(7),
     *                  OBJFN(4),WTOBFN
  690 FORMAT(4(15X,*BOT COMP SPP*,I2,F12.2,F11.2,F9.2         /)1H+,
     *     61X,G10.3/15X,*LIVEWEIGHT*,F14.0,F11.0,F9.0,F12.3//
     *     35X,*SUM OF OBJECTIVE FUNCTIONS*,G15.4/)
  695 KRITM=KRITM+1
      GOTO 100
  700 WRITE(12,805)NZP,NZQ
      WRITE(13,805)NZP,NZQ
      WRITE(13,819)
  819 FORMAT(//*  DAY   LIVEWEIGHT   PASTURE DRY MATTER   PERCENT*,
     1     * GREEN*,29X,*BOTANICAL COMPOSITION*,14X,*OBJECTIVE FUNCT.*
     2     /6X,*DATA MOD DIFF    DATA  MODEL  DIFF*,3X,*DATA MOD DIFF*,
     3     4X,4(*DATA MOD DIFF*,2X),* SIGMA    DIFF*/)
```

```
      DO 817 K=1,15
      DIFF(1)=WTMEAR(K)-SV(1,K)
      DIFF(2)=PASDM(K)-SV(2,K)
      DIFF(3)=PERG(K)-SV(3,K)
      DO 822 I=1,4
  822 DIFF(I+3)=BOTCMP(I,K)-SV(I+3,K)
      ADIFF=0.
      IF(K.EQ.1)GOTO 817
      ADIFF=SV(8,K)-SV(8,K-1)
  817 WRITE(13,824)NDAYY(K),WTMEAR(K),SV(1,K),DIFF(1),PASDM(K),SV(2,K),
     1    DIFF(2),PERG(K),SV(3,K),DIFF(3),(BOTCMP(J,K),SV(J+3,K),
     2    DIFF(J+3),J=1,4),SV(8,K),ADIFF
  824 FORMAT(I5,3F5.0,F7.0,2F6.0,F7.2,2F5.2,3X,12F5.2,2F8.1)
      WRITE(13,838)BIAS(7),(BIAS(J),J=1,6)
  838 FORMAT(*-MEAN BIAS*,F10.0,F19.0,F17.2,3X,4F15.2)
      WRITE(13,842)OBJFN(4),(OBJFN(J),J=1,3)
  842 FORMAT(*-OBJFN CONTRIB*,F6.1,F19.1,F17.1,F33.1)
      T11=T11+WTOBJFN
      WRITE(11,707)NST,WTOBFN
  707 FORMAT(I6,F11.0)
      IF(NST.EQ.NSET)GOTO 600
      NS=(NSET-NST)*19
      DO 710 I=1,NS
  710 BACKSPACE 60
  600 CONTINUE
      NST=6H=TOTAL
      WRITE(11,709)NST,T11
  709 FORMAT(A6,F11.0)
 1111 FORMAT(I1,*DAY  GDM   DDM  TOTAL      PGROTH*,11X,*BOT.*,
     1  *COMPOSITION  INT TMP RAIN SENC SENT DDAY   WT*,
     2   *  LWC  TOTSM DIG    N  FIB RAT*/
     3   24X,2(* 1     2    3    4     *))
 1112 FORMAT(I4,2F6.0,F7.0,F4.0,3F5.0,4F5.2,F4.1,F4.0,F5.1,
     1   3F5.3,F6.0,F4.1,F6.0,2F5.2,F5.0,F5.2)
      END
```

```
      SUBROUTINE FTLIZE(NPADOC,NTYPE,AMT)
C
C  **  SUBROUTINE FTLIZE HANDLES THE BOOK-KEEPING ASSOCIATED WITH THE
C      APPLICATION OF FERTILIZER TO PADDOCK(NPADOC).
C
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION NT(2)
      DATA NT/8H SUPER   ,8HNITROGEN/
C
C   VARIABLE          MEANING
C
C      A       CONSTANT DEFINING RESPONSE TO FERTILIZER. HELD IN DATA STATEMENT
C      B       CONSTANT DEFINING RESPONSE TO FERTILIZER. HELD IN DATA STATEMENT
C      C       CONSTANT DEFINING RESPONSE TO FERTILIZER. HELD IN DATA STATEMENT
C      AMT     AMOUNT OF FERTILIZER (KG/HA SUPER),(KG N/HA) APPLIED
C    FERTAN    ACTUAL N FERTILITY OF SOIL
C    FERTAP    ACTUAL P FERTILITY OF SOIL
C    FERTNT    NO DAYS SINCE NITROGEN FERTILIZER WAS APPLIED
C    FERTPT    NO DAYS SINCE PHOSPHOROUS FERTILIZER WAS APPLIED
C     FMAXN    N FERTILITY AFTER APPLICATION OF N FERTILIZER
C     FMAXP    P FERTILITY AFTER APPLICATION OF P FERTILIZER
C     IAMT     INTEGER AMT FOR OUTPUT USE ONLY
C    NPADOC    INDEX OR FLAG DEFINING PADDOCK NO.
C    NTYPE     FORMAL PARAMETER DEFINING FERTILIZER TYPE. 0=SUPER, 1=NITROGEN
C    RSPNSE    RESPONSE TO FERTILIZER,ADDED ONTO FERTAN(P) TO GIVE FMAXN(P)
C
      IAMT=AMT
      J=NTYPE+1
      IF(NTYPE.EQ.1)GOTO 100
      RSPNSE=AMT*.0025
      FERTAP(NPADOC)=FERTAP(NPADOC)+RSPNSE
      FERNEW=FERTAP(NPADOC)
      GOTO 9
  100 RSPNSE=AMT*.00160
      FERTAN(NPADOC)=FERTAN(NPADOC)+RSPNSE
      FERNEW=FERTAN(NPADOC)
    9 WRITE(1,20)LDAY,IAMT,NT(J),NPADOC,RSPNSE,FERNEW
   20 FORMAT(* ON DAY*,I4,*,*I4,* KG *,A8,* WAS APPLIED TO PADDOCK*,I2,
     1 *. THE RESPONSE WAS*,F4.2,* HENCE FERTILITY IS NOW*,F5.2)
      RETURN
      END
```

```
      SUBROUTINE BREED(NP,LDAY)
C
C  **  SUBROUTINE BREED COMPUTES THE NUMBER OF EMPTY COWS BECOMING PREGNANT I
C      THE MATING PERIOD. THIS INVOLVES A RANDOM SAMPLING FROM THE BINOMIAL
C      DISTRIBUTION WITH THE PROBABILITY OF PREGNANCY DEFINED FROM 'PREGGO'
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
C
C   VARIABLE            MEANING
C
C    AVWTCH     AVERAGE WEIGHT CHANGE OVER LAST 14 DAYS FOR I-TH CLASS,J-TH PD
C      C        INTERMEDIATE VARIABLE
C     N1        INTERMEDIATE VARIABLE
C    NCLASS     CLASS OF ANIMAL BEING CONSIDERED
C    NDPREG     NUMBER OF DAYS PREGNANT FOR CLASS 3 OR 5 COWS IN THE J-TH PDK
C    NOANIM     NO. ANIMALS IN THE I-TH CLASS,GRAZING THE J-TH PADDOCK
C      NP       PADDOCK IN WHICH BREEDING IS TO TAKE PLACE
C      P        PROBABILITY OF PREGNANCY
C      W        WEIGHT OF ANIMALS IN NCLASS-CLASS,WHICH ARE TO BE JOINED
C      WT       WEIGHT(KG) OF THE I-TH CLASS OF ANIMAL IN THE J-TH PADDOCK
C     WTAV      LAST 14 DAYS WTGAINS FOR I-TH CLASS IN J-TH PADDOCK,K DAY AGO
C
      INDEX=0
      DO 100 NCLASS=2,4,2
      IF(NOANIM(NCLASS,NP).EQ.0)GOTO 100
      INDEX=INDEX+1
      IF(INDEX.EQ.1)WRITE(1,20)NP,LDAY
   20 FORMAT(*-BREEDING OF COWS IN PADDOCK*,I2,* ON DAY*,I4/
     1    *       CLASS     NUMBER     WEIGHT   PROBABILITY OF     NUMBER*/
     2    *                                       CONCEPTION     CONCEIVING*)
      N=NOANIM(NCLASS,NP)
      L=NCLASS/2-1
      W=WT(NCLASS,NP)
      C=AVWTCH(NCLASS,NP)
      P=PREGGO(W,C,L)
      M=NBUN(N,P)
      WRITE(1,30)NCLASS,N,W,P,M
   30 FORMAT(I8,I10,F11.0,F13.3,I13)
      IF(M.EQ.0)GOTO 100
      NDPREG(NP)=1
      N1=NOANIM(NCLASS+1,NP)
      NOANIM(NCLASS+1,NP)=M+N1
      NOANIM(NCLASS,NP)=N-M
      WT(NCLASS+1,NP)=(WT(NCLASS,NP)*N+WT(NCLASS+1,NP)*N1)/(N+N1)
      AVWTCH(NCLASS+1,NP)=(AVWTCH(NCLASS,NP)*N+AVWTCH(NCLASS+1,NP)*N1)
     *                    /(N+N1)
      WTMAX(NCLASS+1,NP)=(WTMAX(NCLASS,NP)*N+WTMAX(NCLASS+1,NP)*N1)
     *                    /(N+N1)
      DO 10 J=1,14
   10 WTAV(NCLASS+1,NP,J)=(WTAV(NCLASS,NP)*N+WTAV(NCLASS+1,NP)*N1)/
     *                    (N+N1)
  100 CONTINUE
      IF(INDEX.NE.0)CALL STAN
      RETURN
      END
```

```
      SUBROUTINE DROP(NP,LDAY)
C
C  **  THIS SUBROUTINE HANDLES THE CALVING IN A HERD. THE BOOK-KEEPING IS DONE
C      AND THE MORTALITY OF CALVES DETERMINED
C
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
C
C    AVWTCH    AVERAGE WEIGHT CHANGE OVER LAST 14 DAYS FOR I-TH CLASS,J-TH PD
C      N       INTERMEDIATE VARIABLE
C     N2       INTERMEDIATE VARIABLE
C     NDIE     NO. CALVES THAT DIE AT BIRTH
C    NDSUCK    NUMBER OF DAYS SINCE BIRTH OF CALVES
C    NOANIM    NO. ANIMALS IN THE I-TH CLASS,GRAZING THE J-TH PADDOCK
C      NP      PADDOCK IN WHICH CALVING TAKES PLACE
C      P       PROBABILITY OF CALF MORTALITY AT BIRTH
C      WT      WEIGHT(KG) OF THE I-TH CLASS OF ANIMAL IN THE J-TH PADDOCK
C     WTAV     LAST 14 DAYS WTGAINS FOR I-TH CLASS IN J-TH PADDOCK,K DAY AGO
C
      NSUM(N,M)=MAX0(N+M,1)
      CALL WEAN(NP,NP,LDAY)
      IF(NOANIM(3,NP).EQ.0)RETURN
      N=NOANIM(3,NP)
      NOANIM(3,NP)=0
      NOANIM(6,NP)=N
      WT(6,NP)=16.4+0.032*WT(3,NP)
      NSV=N
      P=0.0
C
C  THE PARAMETER P DETERMINES THE PROBABILITY OF CALF MORTALITY AT BIRTH
C  IT WOULD BE A FUNCTION OF COW WT AND, POSSIBLY, WT CHANGE
C
      NDIE=NBUN(N,P)
      N=N-NDIE
      WSV=WT(3,NP)
      WT(3,NP)=WT(3,NP)-1.5*WT(6,NP)
      WRITE(1,30)NP,LDAY,NSV,WSV,P,NDIE,N,WT(6,NP)
   30 FORMAT(*-CALVING IN PADDOCK*,I2,* ON DAY*,I4,*,*/
     1 *       NUMBER     WEIGHT    PROBABILITY     NUMBER    NUMBER*,
     2*   WEIGHT*/6X,*COWS*,14X,*OF MORTALITY   DYING     CALVES*/
     3I9,F11.0,F12.3,I11,I9,F10.0/)
      NDSUCK(NP)=0
      NDPREG(NP)=-999
      N2=NOANIM(2,NP)
      WT(2,NP)=(WT(2,NP)*N2+WT(3,NP)*NDIE)/NSUM(N2,NDIE)
      AVWTCH(2,NP)=(AVWTCH(2,NP)*N2+AVWTCH(3,NP)*NDIE)/NSUM(N2,NDIE)
      WTMAX(2,NP)=(WTMAX(2,NP)*N2+WTMAX(3,NP)*NDIE)/NSUM(N2,NDIE)
      DO 10 K=1,14
   10 WTAV(2,NP,K)=(WTAV(2,NP,K)*N2+WTAV(3,NP,K)*NDIE)/NSUM(N2,NDIE)
      NOANIM(2,NP)=N2+NDIE
      N2=NOANIM(4,NP)
      NOANIM(4,NP)=NOANIM(4,NP)+N
      WT(4,NP)=(WT(4,NP)*N2+WT(3,NP)*N)/NSUM(N2,N)
      AVWTCH(4,NP)=(AVWTCH(4,NP)*N2+AVWTCH(3,NP)*N)/NSUM(N2,N)
      WTMAX(4,NP)=(WTMAX(4,NP)*N2+WTMAX(3,NP)*N
     1          -2.0*WT(6,NP)*N)/NSUM(N2,N)
      DO 20 K=1,14
   20 WTAV(4,NP,K)=(WTAV(4,NP,K)*N2+WTAV(3,NP,K)*N)/NSUM(N2,N)
      CALL STAN
```

```
      RETURN
      END


      FUNCTION PREGGO(WT,WC,L)
C
C  **  'PREGGO' COMPUTES THE PROBABILITY OF PREGNANCY OF A GIVEN COW CLASS
C
C
C  PREGNANCY IS CONSIDERED AS A BINOMIALLY DISTRIBUTED
C  VARIABLE WITH THE PROBABILITY OF PREGNANCY BEING A FUNCTION OF
C      1. BODYWEIGHT
C      2. WEIGHT GAIN OVER THE LAST 14 DAYS
C      3. WHETHER THE ANIMAL IS LACTATING,AND IF SO HER MILK YIELD
C  ENTER SUBROUTINE WITH WEIGHT(WT),WEIGHT CHANGE OVER LAST 14 DAYS(WC)
C  AND LACTATION STATUS(L=0 FOR NOT LACTATING,L=1 FOR LACTATING),
C  THE PROBABILITY OF CONCEPTION IS THEN RETURNED IN VARIABLE PREGGO
C
      BW=WT
      AL=L
      PREGGO=-.9896+.00697*BW-.5966E-5*BW*BW+.35858*WC
     1      -AL*.1661
      PREGGO=AMIN1(.96,AMAX1(.02,PREGGO))
      RETURN
      END


      FUNCTION ANORM(X)
C
C  **  'ANORM' CALCULATES A RANDOM NORMAL DEVIATE
C  USING THE METHOD OF BOX AND MULLER(1958)
C
C
C   VARIABLE          MEANING
C
C      R1     RANDOM NUMBER
C      R2     RANDOM NUMBER
C      X1     INTERMEDIATE VARIABLE
C
      R1=RANF(-1)
      R2=RANF(-1)
      X1=-2.0*ALOG(R1)
      ANORM=SQRT(X1)*SIN(6.2831854*R2)
      RETURN
      END
```

```
      FUNCTION NBUN(NUMB,PROB)
C
C  **  'NBUN' IS A FUNCTION SUBPROGRAM WHICH ALLOWS A RANDOM SAMPLING FROM
C       A BINOMIAL DISTRIBUTION OF NUMBER, NUMB, AND PROBABILITY, PROB
C
C
C  IF N IS GREATER THAN 147 THEN FACTORIAL N CAUSES EXPONENT OVERFLOW
C  THUS A NORMAL APPROXIMATION TO THE BINOMIAL IS ASSUMED
C
      N=NUMB
      P=PROB
      Q=1.-P
      IF(N.LE.147)GOTO 5
      G=ANORM(0)
      VAR=N*P*Q
      D=N*P+G*SQRT(VAR)
      J=D+.5
      J=MAX0(0,J)
      J=MIN0(J,N)
      GOTO 40
    5 CUMPRB=0.0
      RN=RANF(-1)
      M=N+1
      D=FACT(N)
      DO 30 I=1,M
      J=I-1
      K=N-J
      IF(J.EQ.0.OR.J.EQ.N)GOTO 10
      F=D/(FACT(J)*FACT(K))
      GOTO 20
   10 F=1.0
   20 G=(P**J)*(Q**K)
      CUMPRB=CUMPRB+F*G
      IF (CUMPRB.GT.RN)GOTO 40
   30 CONTINUE
      J=N
   40 NBUN=J
      RETURN
      END
```

```
      SUBROUTINE WEAN(NP,MP,LDAY)
C
C  **  WEAN HANDLES THE WEANING OF CALVES PADDOCK NP TO MP
C
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
C
C    VARIABLE       MEANING
C
C     AVWTCH    AVERAGE WEIGHT CHANGE OVER LAST 14 DAYS FOR I-TH CLASS,J-TH PD
C       F1      INTERMEDIATE VARIABLE
C       F2      INTERMEDIATE VARIABLE
C       MP      PADDOCK INTO WHICH WEANED CALVES ARE TO BE PLACED
C       N       INTERMEDIATE VARIABLE
C       N1      INTERMEDIATE VARIABLE
C       NB      NO. STEERS IN PADDOCK INTO WHICH CALVES ARE WEANED
C     NBULL     NO. MALE VALVES IN PADDOCK NP
C       NC      NO. COWS IN PADDOCK INTO WHICH VALVES ARE WEAVED
C      NCOW     NO. FEMALE CALVES IN PADDOCK NP
C     NDWEAN    NUMBER OF DAYS SINCE CALVES WERE WEANED
C     NOANIM    NO. ANIMALS IN THE I-TH CLASS,GRAZING THE J-TH PADDOCK
C       NP      PADDOCK FROM WHICH WEANING TAKES PLACE
C       W       INTERMEDIATE VARIABLE
C       W1      INTERMEDIATE VARIABLE
C       WT      WEIGHT OF ANIMALS IN I-TH CLASS, J-TH PADDOCK
C      WTAV     LAST 14 DAYS WTGAINS FOR I-TH CLASS IN J-TH PADDOCK,K DAY AGO
C     WTBULL    WEIGHT OF MALES WEANED
C     WTCOW     WEIGHT OF WEANED REMALES
C
      NSUM(K,L)=MAX0(K+L,1)
      INDEX=0
      DO 100 J=4,5
      IF(NOANIM(J,NP).EQ.0)GOTO 100
      INDEX=INDEX+1
      IF(INDEX.EQ.1)WRITE(1,30)NP,MP,LDAY
   30 FORMAT(*-WEANING OF CALVES IN PADDOCK*,I2,* TO PADDOCK*,I2,
     1       * REQUESTED ON DAY*,I4,*.*/
     2*  CLASS    NUMBER
     3* OF COWS    COWS                          CALVES*/
     4*                               MALES                 FEMALES*/
                              NUMBER    WEIGHT      NUMBER    WEIGHT*)
      N=NOANIM(J,NP)
      W=WT(J,NP)
      N1=NOANIM(J-2,NP)
      W1=WT(J-2,NP)
      NOANIM(J,NP)=0
      NOANIM(J-2,NP)=N+N1
      WT(J-2,NP)=(W*N+W1*N1)/NOANIM(J-2,NP)
      F1=N/NOANIM(J-2,NP)
      F2=N1/NOANIM(J-2,NP)
      AVWTCH(J-2,NP)=AVWTCH(J-2,NP)*F2+AVWTCH(J,NP)*F1
      DO 10 K=1,14
      WTAV(J-2,NP,K)=WTAV(J-2,NP,K)*F2+WTAV(J,NP,K)*F1
   10 CONTINUE
      NOANIM(6,NP)=NOANIM(6,NP)-N
      NBULL=NBUN(N,.5)
      NCOW=N-NBULL
      WTCOW=10.*WT(6,NP)/(10*NCOW+10*NBULL)
      WTBULL=1.0*WTCOW
      WRITE(1,40)J,N,NBULL,WTBULL,NCOW,WTCOW
```

```
   40 FORMAT(I5,I10,I11,F10.0,I10.0,F10.0)
      NC=NOANIM(2,MP)
      NB=NOANIM(1,MP)
      NOANIM(1,MP)=NB+NBULL
      NOANIM(2,MP)=NC+NCOW
      WT(1,MP)=(WT(1,MP)*NB+WTBULL*NBULL)/NSUM(NB,NBULL)
      WT(2,MP)=(WT(2,MP)*NC+WTCOW*NCOW)/NSUM(NC,NCOW)
      NDWEAN(MP)=0
      NDSUCK(NP)=-999
      AVWTCH(1,MP)=(AVWTCH(1,MP)*NB+AVWTCH(6,NP)*NBULL)/NSUM(NB,NBULL)
      AVWTCH(2,MP)=(AVWTCH(2,MP)*NC+AVWTCH(6,NP)*NCOW)/NSUM(NC,NCOW)
      WTMAX(1,MP)=(WTMAX(1,MP)*NB+WTBULL*NBULL)/NSUM(NB,NBULL)
      WTMAX(2,MP)=(WTMAX(2,MP)*NC+WTCOW*NCOW)/NSUM(NC,NCOW)
      DO 20 K=1,14
      WTAV(1,MP,K)=(WTAV(1,MP,K)*NB+WTAV(6,NP,K)*NBULL)/NSUM(NB,NBULL)
   20 WTAV(2,MP,K)=(WTAV(2,MP,K)*NC+WTAV(6,NP,K)*NCOW)/NSUM(NC,NCOW)
  100 CONTINUE
      IF(INDEX.NE.0)CALL STAN
      RETURN
      END


      FUNCTION RAINRV(DAY)
C
C  **  'RAINRV' DETERMINES THE RANDOM VARIABLE OF THE RAINFALL DISTRIBUTION
C
C
C  IN THIS FUNCTION SUBPROGRAM THE ACTUAL RAINFALL IS CALCULATED
C  AS A RANDOM VARIABLE FROM A DISTRIBUTION OF MEAN 1 AND WITH A
C  RATIO OF STANDARD DEVIATION TO MEAN OF ABOUT 1.6. THIS DISTRIBUTION
C  FALLS AWAY QUICKLY, IN A SIMILAR MANNER TO A CHI-SQUARED DISTRIBUTION
C  WITH ONE DEGREE OF FREEDOM
C
      X=ANORM(0)
      X=ABS(X)
      X=X**2.3
      RAINRV=X/1.12
      RETURN
      END
```

```
      SUBROUTINE MOVEAV(MOVEIN)
C
C  **  'MOVEAV' IS A BOOK-KEEPING ROUTINE WHICH ALSO CALCULATES THE MEAN
C      LIVEWEIGHT GAIN OVER THE PAST 14 DAYS
C
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      COMMON /PLOT/NUMPLT(6),NPLOTT(60),AVPGRO(4,4),AVEVAC,AVEVPT,
     *              AVEVRT,AVSAVE(8,4,14),INTPLT,AVSM
C
C  VARIABLE        MEANING
C
C    AVWTCH    AVERAGE WEIGHT CHANGE OVER LAST 14 DAYS FOR I-TH CLASS,J-TH PD
C    NDPREG    NUMBER OF DAYS PREGNANT FOR CLASS 3 OR 5 COWS IN THE J-TH PDK
C    NDSUCK    NUMBER OF DAYS SINCE BIRTH OF CALVES
C    NOANIM    NO. ANIMALS IN THE I-TH CLASS,GRAZING THE J-TH PADDOCK
C    NPADOK    NUMBER OF PADDOCKS IN SYSTEM UNDER STUDY
C      WT      WEIGHT(KG) OF THE I-TH CLASS OF ANIMAL IN THE J-TH PADDOCK
C     WTAV     LAST 14 DAYS WTGAINS FOR I-TH CLASS IN J-TH PADDOCK,K DAY AGO
C
      NM=MOVEIN+1
      IF(NM.EQ.15)NM=1
      DO 100 J=1,NPADOK
      NDSUCK(J)=NDSUCK(J)+1
      NDWEAN(J)=NDWEAN(J)+1
      NDPREG(J)=NDPREG(J)+1
      DO 20 I=1,6
      IF(NOANIM(I,J).EQ.0)GOTO 20
      WTAV(I,J,MOVEIN)=WT(I,J)
      AVWTCH(I,J)=(WTAV(I,J,MOVEIN)-WTAV(I,J,NM))/14.0
   20 CONTINUE
      AVSAVE(5,J,MOVEIN)=EVACT
      AVSAVE(6,J,MOVEIN)=EVPOT
      AVSAVE(7,J,MOVEIN)=RATIO
      AVSAVE(8,J,MOVEIN)=TOTSM
      DO 25 I=1,4
   25 AVSAVE(I,J,MOVEIN)=PGROTH(I,J)
      CALL FERTIL(1,J)
      IF(NOANIM(4,J).EQ.0.AND.NOANIM(5,J).EQ.0)GOTO 50
      IF(NDSUCK(J).LT.300)GOTO 30
      CALL WEAN(J,J,LDAY)
      GOTO 50
   30 DO 40 I=1,2
      IF(NOANIM(I+3,J).EQ.0)GOTO 40
      IF(ACTMLK(I,J).GT.1.0)GOTO 40
      CALL WEAN(J,J,LDAY)
      ACTMLK(I,J)=0.0
      POTYLD(I,J)=0.0
   40 CONTINUE
   50 IF(NOANIM(3,J).EQ.0)GOTO 55
      IF(NDPREG(J).LT.280)GOTO 55
      CALL DROP(J,LDAY)
```

```
      NDSUCK(J)=0
      CALL MILK(4,J)
      NDSUCK(J)=1
   55 IF((LDAY+INTPLT-1)/INTPLT.EQ.(INTPLT+LDAY-2)/INTPLT)GOTO 82
      AVEVAC=0.0
      AVEVPT=0.0
      AVEVRT=0.0
      AVSM=0.0
      DO 60 I=1,4
   60 AVPGRO(I,J)=0.0
      DO 70 K=1,14
      AVEVAC=AVEVAC+AVSAVE(5,J,K)
      AVEVPT=AVEVPT+AVSAVE(6,J,K)
      AVEVRT=AVEVRT+AVSAVE(7,J,K)
      AVSM=AVSM+AVSAVE(8,J,K)
      DO 70 I=1,4
   70 AVPGRO(I,J)=AVPGRO(I,J)+AVSAVE(I,J,K)
      AVEVAC=AVEVAC/14.0
      AVEVPT=AVEVPT/14.0
      AVEVRT=AVEVRT/14.0
      AVSM=AVSM/14.0
      DO 80 I=1,4
   80 AVPGRO(I,J)=AVPGRO(I,J)/14.0
   82 DO 90 I=1,6
      IF(NOANIM(I,J).EQ.0)GOTO 90
      IF(WT(I,J).LE.WTMAX(I,J)) GOTO 85
      WTMAX(I,J)=WT(I,J)
   85 WTDIFF=WTMAX(I,J)-WT(I,J)
      PERWTL=WTDIFF/WTMAX(I,J)
      IF(PERWTL.LE..15)GOTO 90
      PRBDTH =((PERWTL-0.15)**3)*NOANIM(I,J)*.3
      RN=RANF(-1)
      IF(RN.GT.PRBDTH)GOTO 90
      IF(I.EQ.4.OR.I.EQ.5)NOANIM(6,J)=NOANIM(6,J)-1
      NOANIM(I,J)=NOANIM(I,J)-1
       WRITE(1,95)I,J,LDAY,NOANIM(I,J),WT(I,J),WTMAX(I,J)
   95 FORMAT(*-ANIMAL IN CLASS*,I2,* PADDOCK*,I2,* DIED ON DAY*,I4,
     *       *. THIS LEAVES*,I3,* REMAINING IN THE CLASS.*,
     */* CURRENT WEIGHT IS*,F5.0,* MAXIMUM WEIGHT REACHED WAS*,F5.0)
      IF(I.NE.6)GOTO 90
      IF(NOANIM(6,J).EQ.NOANIM(4,J)+NOANIM(5,J))GOTO 90
      NDIFF=NOANIM(4,J)+NOANIM(5,J)-NOANIM(6,J)
      D=NOANIM(4,J)/(NOANIM(4,J)+NOANIM(5,J))
      M=2
      IF(RANF(-1).GT.D)M=3
      NOANIM(M+2,J)=NOANIM(M+2,J)-NDIFF
      NOANIM(M,J)=NOANIM(M,J)+NDIFF
      WT(M,J)=WT(M+2,J)
      WTMAX(M,J)=WTMAX(M+2,J)
   90 CONTINUE
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SINSOL(I)
C
C  **  SINSOL IS A SUBROUTINE WHICH SOLVES THE EQUATIONS FORMED BY THE VALUES
C      READ INTO ARRAY TEMFAC. THESE VALUES STATE WHERE THE TEMPERATURE RESPONSE
C      CURVE WILL BEGIN, MAXIMIZE AND END. SINSOL THEN DETERMINES THE VALUE
C      OF THE CONSTANTS THAT ARE USED IN FUNCTION HUMP
C
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGRDTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
C
C   VARIABLE            MEANING
C
C      D1        RANGE OVER WHICH TEMPF INCREASES
C      D2        RANGE OVER WHICH TEMPF DECREASES
C       I        DEFINES THE PASTURE SPECIES WHICH IS BEING CONSIDERED
C    TEMFAC      CONSTANTS DEFINE RESPONSE CURVE OF PLANT TO TEMPERATURE
C
C  THIS SUBROUTINE DETERMINES THE VALUE OF THE 4 CONSTANTS:A1,B1,A2,B2
C  GIVEN VALUES FOR A,B AND C.
C                    VALUE OF X                      VALUE OF FUNCTION
C                    LESS THAN A                             0
C          GREATER THAN A,LESS THAN B              (SIN(A1*X+B1)+1)/2
C          GREATER THAN B,LESS THAN C              (SIN(A2*X+B2)+1)/2
C                   GREATER THAN C                           0
C
      D1=TEMFAC(I,2)-TEMFAC(I,1)
      D2=TEMFAC(I,3)-TEMFAC(I,2)
      TEMFAC(I,4)=3.14159/D1
      TEMFAC(I,6)=-3.14159/D2
      TEMFAC(I,5)=-TEMFAC(I,2)/D1+.5
      TEMFAC(I,5)=TEMFAC(I,5)*3.14159
      TEMFAC(I,7)=.5+TEMFAC(I,2)/D2
      TEMFAC(I,7)=TEMFAC(I,7)*3.14159
      DO 10 J=5,7,2
      K=TEMFAC(I,J)/6.28319
   10 TEMFAC(I,J)=TEMFAC(I,J)-K*6.28319
      RETURN
      END


      FUNCTION HUMP(A,B,C,A1,B1,A2,B2,X)
C
C  **  A FUNCTION SUBPROGRAM TO BE USED IN CONJUNCTION WITH SUBROUTINE SINSOL.
C      THIS FUNCTION DETERMINES THE VALUE OF TEMPF, THE TEMPERATURE FACTOR, FOR
C      EACH OF THE PASTURE SPECIES.
C
      IF(X-A)10,10,20
   10 HUMP=0.0
      GOTO 90
   20 IF(C-X)10,30,30
   30 IF(X-B)40,40,50
   40 HUMP=(SIN(A1*X+B1)+1.)/2.
      GOTO 90
   50 HUMP=(SIN(A2*X+B2)+1.0)/2.0
   90 RETURN
      END
```

```
      SUBROUTINE STATUS
C
C   **  A SUBROUTINE TO PROVIDE AN INDICATION OF THE STATUS OF SOIL MOISTURE,
C       PASTURE AND THE ANIMALS ON THE PASTURE
C
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      DIMENSION SPPNAM(8),SAVE(5,4),TOTAL(4),NDY(12),MONTH(12)
      DIMENSION TITLE(12),NFORM(6)
      DATA SPPNAM/6HCARPET,6H GRASS,6HPASPAL,6HUM                     ,
     *6HKIKUYU,6H      ,6HWHITE ,6HCLOVER/,M/7H(KG/HA)/
      DATA MONTH/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJUL,3HAUG,3HSEP,
     *3HOCT,3HNOV,3HDEC/,NDY/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA TITLE/10HRAINFALL (,10HMM)       ,10HSOIL MOIST,
     1          10HURE (MM)  ,10HEVAP RATIO,10H          ,
     2          10HPOT EVAPOT,10HRAN (MM)  ,10HACT EVAPOT,
     3          10HRAN (MM)  ,10HTEMPERATUR,10HE (DEG C) /
      DATA NFORM/2*0,2,2*1,0/
      WRITE(1,10)LDAY,TOTSM
   10 FORMAT(*-CALL TO STATUS MADE ON DAY*,I4/* SOIL MOISTURE LEVEL*,
     *F5.0,* MM*)
      DO 100 N=1,NPADOK
      WRITE(1,20)N
   20 FORMAT(*-PADDOCK*,I2)
      INDEX=0
      DO 30 I=1,6
      IF(NOANIM(I,N).EQ.0)GOTO 30
      IF(INDEX.EQ.0)WRITE(1,25)
   25 FORMAT(* CLASS          NUMBER              WEIGHT         AVERAGE WT CHANGE*
     1/29X,*(KG)*,6X,*OVER 14 DAYS, KG/DAY*)
      INDEX=INDEX+NOANIM(I,N)
      WRITE(1,35)I,NOANIM(I,N),WT(I,N),AVWTCH(I,N)
   30 CONTINUE
   35 FORMAT(I4,I13,F16.0,F18.1)
      IF(INDEX.EQ.0)GOTO 50
      WRITE(1,40)INDEX
   40 FORMAT(7X,*TOTAL*,I5/)
   50 WRITE(1,60)M,M,M,M
   60 FORMAT(*     SPECIES     GROUND*,3(5X,*WEIGHT OF*),6X,*TOTAL*,
     A6X,*BOTANICAL*/
     1         16X,*COVER*,6X,*GREEN-LEAF*,8X,*DRY*,5X,*INFLORESCENCE*,
     2         3X,*WEIGHT*,6X,*COMPOSITION*/21X,4(7X,A7),4X,*(DM BASIS)*)
      DO 80 NS=1,4
      SAVE(1,NS)=0.0
      SAVE(2,NS)=PLANT(5,NS,N)
      SAVE(3,NS)=PLANT(6,NS,N)
      DO 65 I=1,4
   65 SAVE(1,NS)=SAVE(1,NS)+PLANT(I,NS,N)
      SAVE(4,NS)=SAVE(1,NS)+SAVE(2,NS)+SAVE(3,NS)
      SAVE(5,NS)=PERCEN(NS,N)*SAVE(4,NS)/PTOTAL(N)
      WRITE(1,70)SPPNAM(2*NS-1),SPPNAM(2*NS),PERCEN(NS,N),
     *          (SAVE(K,NS),K=1,5)
```

```
   70 FORMAT(2X,2A6,F6.2,4F14.0,F11.2)
      TOTAL(NS)=0.0
   80 CONTINUE
      DO 85 NS=1,4
      DO 85 J=1,3
   85 TOTAL(J)=TOTAL(J)+SAVE(J,NS)*PERCEN(NS,V)
      WRITE(1,90)(TOTAL(K),K=1,3),PTOTAL(V)
   90 FORMAT(*           WEIGHTED TOTALS*,F11.0,3F14.0/)
      WRITE(1,95)FERTN(N),FERTAN(N),FERTP(N),FERTAP(N)
   95 FORMAT(/17X,*FERTILITY STATUS*/18X,*BASE*,5X,*ACTUAL*/
     *     15H      NITROGEN ,F7.2,F10.2/15H    PHOSPHOROUS ,F7.2,F10.2/)
  100 CONTINUE
      RETURN
      ENTRY YRSUM
      WRITE(1,110)LCALL,(MONTH(K),K=1,12)
  110 FORMAT(//50X,*CLIMATIC SUMMARY FOR YEAR*,I3//25X,12(2X,A3,3X),
     *          3X,*TOTAL*/)
      DO 120 I=1,12
      DO 120 J=1,6
  120 SUMYR(J)=SUMYR(J)+SUMMON(J,I)
      DO 140 J=2,6
      DO 130 I=1,12
  130 SUMMON(J,I)=SUMMON(J,I)/NDY(I)
  140 SUMYR(J)=SUMYR(J)/365.
      DO 180 K=1,6
      J=2*K
      I=J-1
      WRITE(1,150)(TITLE(L),L=I,J)
  150 FORMAT(1X,2A10)
      DO 160 L=1,12
      NL=22+8*L
      WRITE(1,170)NL,NFORM(K),SUMMON(K,L)
  160 CONTINUE
  170 FORMAT(1H+,F=.=)
      WRITE(1,190)NFORM(K),SUMYR(K)
  180 CONTINUE
  190 FORMAT(1H+,F128.=)
      RETURN
      END
```

```
      SUBROUTINE SUBREC
C
C  **  'SUBREC' CALCULATES SOME OF THE SOIL MOISTURE CONSTANTS AND PRINTS THEIR
C      VALUES OUT, IT IS ONLY CALLED ONCE IN THE PROGRAM.
C
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION WHC(2)
C
C   VARIABLE          MEANING
C
C      FC       FIELD CAPACITY OF SOIL LAYERS (FRACTION)
C      FC1      FIELD CAPACITY IN LEVEL 1 OF SOIL(MM)
C      FC2      FIELD CAPACITY IN LEVEL 2 OF SOIL(MM)
C      FS       FIELD SATURATION (FRACTION)
C      FS1      FIELD SATURATION(MM) IN THE FIRST SOIL LEVEL
C      FS2      FIELD SATURATION(MM) IN THE SECOND SOIL LEVEL
C    HORIZD     DEPTH (CM) OF SOIL LAYERS
C    PENMAN     PARAMETER IN RANGE (.6,.8) DEFINING EVPOT FROM PAN EVAPORATION
C      SM       SOIL MOISTURE (FRACTION)
C      SM1      SOIL MOISTURE IN THE FIRST SOIL LEVEL(MM)
C      SM2      SOIL MOISTURE IN THE SECOND SOIL LEVEL(MM)
C     TEMP      TEMPERATURE
C    TOTSM      TOTAL SOIL MOISTURE IN THE SOIL(MM)
C     TRMAX     MAXIMUM TRANSPIRATION RATES OF SOIL LAYERS
C    WATCAP     MOISTURE HOLDING CAPACITY OF SOIL AT FIELD CAPACITY AND SATURATN
C      WHC      WATER HOLDING CAPCITY (MM) AT FIELD CAPACITY AND FIELD SATURATN
C      WP       WILTING POINT OF I-TH SOIL LAYER(FRACTION)
C      WP1      WILTING POINT(MM) IN THE FIRST SOIL LEVEL
C      WP2      WILTING POINT(MM) IN THE SECOND SOIL LEVEL
C
      SM1=SM(1)*HORIZD(1)
      SM2=SM(2)*HORIZD(2)
      FC1=FC(1)*HORIZD(1)
      FC2=FC(2)*HORIZD(2)
      WP1=WP(1)*HORIZD(1)
      WP2=WP(2)*HORIZD(2)
      FS1=FS(1)*HORIZD(1)
      FS2=FS(2)*HORIZD(2)
      TOTSM=SM1+SM2
      IF(NPRSUM.EQ.0)GOTO 55
      WRITE(1,10)TEMP,PENMAN
   10 FORMAT(       //40X,*INITIAL CONDITIONS AND PARAMETER SETTINGS*//
     *40X,*INITIAL TEMPERATURE*,F10.1,* DEG. C*/
     *40X,*PARAMETER PENMAN IS SET AT*,F4.2//53X,*SOIL PARAMETERS*/
     *46X,*HORIZON 1*,10X,*HORIZON 2*)
      WRITE(1,20)HORIZD,WP,FC,FS,SM
   20 FORMAT(23X,*DEPTH (MM)*,F19.0,F20.0/23X,*WILTING POINT*,F18.2,
     *        F20.2/23X,*FIELD CAPACITY *,F16.2,F20.2/23X,*FIELD STORAGE*
     *        ,F18.2,F20.2/23X,*INITIAL SOIL MOISTURE*,F10.2,F20.2)
      WHC(1)=(FC(1)-WP(1))*HORIZD(1)
      WHC(2)=(FC(2)-WP(2))*HORIZD(2)
      WATCAP(1)=WHC(1)+WHC(2)
      WRITE(1,30)WHC(1),WHC(2),WATCAP(1)
   30 FORMAT(23X,*STORAGE AT FLD CAP (MM) *,F5.0,8X,1H+,F11.0,8X,
     *        1H=,F13.0)
      WHC(1)=FS1-WP1
```

```
      WHC(2)=FS2-WP2
      WATCAP(1)=WHC(1)+WHC(2)
      WRITE(1,32)WHC(1),WHC(2),WATCAP(1)
   32 FORMAT(23X,*STORAGE AT FLD SAT (MM) *,F5.0,8X,1H+,F11.0,8X,
     *         1H=,F13.0)
      WATCAP(2)=WP1+WP2
      WRITE(1,31)WP1,WP2,WATCAP(2)
   31 FORMAT(23X,*WILTING POINT (MM)      *,F5.0,8X,1H+,F11.0,8X,
     *         1H=,F13.0)
      WHC(1)=FC1
      WHC(2)=FC2
      WATCAP(2)=WHC(1)+WHC(2)
      WRITE(1,40)WHC(1),WHC(2),WATCAP(2)
   40 FORMAT(23X,*FIELD CAPACITY (MM)   *,F7.0,8X,1H+,F11,0,
     *         8X,1H=,F13.0)
   55 CONTINUE
      WHC(1)=FS(1)*HORIZD(1)
      WHC(2)=FS(2)*HORIZD(2)
      WATCAP(2)=WHC(1)+WHC(2)
      IF(NPRSUM.EQ.0)GOTO 100
      WRITE(1,42)WHC(1),WHC(2),WATCAP(2)
   42 FORMAT(23X,*FIELD SATURATION (MM) *,F7.0,8X,1H+,F11,0,
     *         8X,1H=,F13.0)
      WRITE(1,50)(TRMAX(J),J=1,2)
   50 FORMAT(23X,*MAX TRAN RATE (MM/HR)*,F10.2,F20.2)
  100 RETURN
      END
```

```
      SUBROUTINE DATOUT
C
C  **  SUBROUTINE DATOUT READS ALL DATA CARDS AND LISTS THEM
C
      DIMENSION NSSP(8)
      NUMBCK=0
      WRITE(1,5)
    5 FORMAT(      /* CARD*,10X,*DATA CARDS*/*  NO*/)
   10 READ(60,20)(NSSP(I),I=1,8)
   20 FORMAT(8A10)
      IF(EOF(60))60,30
   30 NUMBCK=NUMBCK+1
      WRITE(1,40)NUMBCK,(NSSP(I),I=1,8)
   40 FORMAT(I5,5X,8A10)
      GOTO 10
   60 DO 70 I=1,NUMBCK
   70 BACKSPACE 60
      RETURN
      END
```

```
      SUBROUTINE RECORD
C
C  **  THIS SUBROUTINE PRINTS OUT THE INITIAL MESSAGE AND COMMENT CARDS WHICH
C      HAVE BEEN WRITTEN FOR THIS RUN. 'RECORD' ALSO NOTES THE TIME AND DATE
C
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGRUTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION NR(10,10),NASTY(48)
      DATA NASTY/48*8H********/
C
C   VARIABLE          MEANING
C
C     NASTY    ARRAY FULL OF *** FOR TITLE PAGE
C       NR     ARRAY WHICH HOLDS COMMENT CARDS THAT READ IN
C       TI     TIME OF DAY
C       XN     DATE
C
      IF(NPRSUM.EQ.0)GOTO 900
  999 FORMAT(1H1////25X,A8,10X,A7,7X,A8,A5,8X,A8,A6,5X,A4,15X,A4/
     124X,A8,A2,8X,A8,A1,6X,A8,A6,7X,A8,A5,5X,A4,15X,A4/
     223X,A8,A4,6X,A8,A3,5X,A8,A7,6X,A8,A5,5X,A4,15X,A4/
     322X,A3,15X,A4,5X,A3,5X,A4,8X,A4,5X,A4,15X,A4,13X,A4/
     422X,A3,15X,A4,5X,A3,5X,A4,8X,A4,5X,A4,15X,A4,13X,A4)
  998 FORMAT(22X,A3,15X,A4,13X,A4,8X,A4,5X,A4,16X,A4,13X,A4/
     123X,A8,A2,7X,A4,13X,A8,A7,6X,A8,A4,9X,A4,11X,A4/
     224X,A8,A2,6X,A4,13X,A8,A6,7X,A8,A4,9X,A4,3X,A5,3X,A4/
     325X,A8,A2,5X,A4,13X,A8,A6,7X,A8,A4,9X,A4,3X,A5,3X,A4/
     433X,A3,4X,A4,13X,A4,6X,A4,7X,A4,18X,A4,1X,A3,1X,A3,1X,A4)
  997 FORMAT(33X,A3,4X,A4,5X,A3,5X,A4,6X,A4,7X,A4,18X,A4,1X,A3,1X,
     1A3,1X,A4/33X,A3,4X,A4,5X,A3,5X,A4,6X,A4,7X,A4,18X,A4,1X,A3,1X,
     2A3,1X,A4/23X,A8,A4,6X,A8,A3,5X,A4,7X,A4,5X,A8,A6,9X,A6,3X,A6/
     424X,A8,A2,8X,A8,A1,6X,A4,8X,A4,5X,A8,A6,9X,A6,3X,A6/
     525X,A8,10X,A7,7X,A4,8X,A4,5X,A8,A6,9X,A6,3X,A6////)
      WRITE(1,999)(NASTY(I),I=1,44)
      WRITE(1,998)(NASTY(I),I=1,45)
      WRITE(1,997)(NASTY(I),I=1,48)
      WRITE(1,1000)
      XN=DATE(0)
      CALL TIME(TI)
  900 CONTINUE
C
C  READ ANY COMMENT RECORDS IN ON THE FIRST 10 CARDS AFTER THE EOS CARD
C  THESE CARDS MUST BE INCLUDED IN THE DECK, BUT CAN BE BLANK
C
      READ(60,1020)((NR(J,I),J=1,10),I=1,10)
      IF(NPRSUM.EQ.0)RETURN
      WRITE(1,1010)XN,TI
      WRITE(1,1030)NR
 1000 FORMAT(//50X,17H***   SCREW    ***,//37X
     2   *A MODEL OF A BEEF ENTERPRISE OF UP TO 4 PADDOCKS*/35X,
     1   *IN THE HIGH RAINFALL NORTH COAST OF NEW SOUTH WALES*/
     $/40X,*S   SIMULATION OF A*/40X,*C   CATTLE*/40X,*R   RAISING*
     $/40X,*E   ENTERPRISE*/40X,*W   WITH A DIGITAL COMPUTER*///35X
     $26HMODEL WRITTEN BY H.JEFFERY/52X,25HDIVISION OF PLANT INDUSTRY/
     $52X,10HC.S.I.R.O./52X,13HBOX 1600,P.O./52X,13HCANBERRA CITY/
     $52X,11HA.C.T.,2600/)
 1010 FORMAT(40X,6HDATE   ,A9/40X,
     $6HTIME  ,A6          ///50X,17HCOMMENTS THIS RUN  /)
 1020 FORMAT(10A8)
 1030 FORMAT(35X,10A8)
```

```
      RETURN
      END


      SUBROUTINE PARSET
C
C  **  SUBROUTINE PARSET IS USED TO SET THE INITIAL VALUES TO THE COEFFICIENTS
C      USED IN THE PASTURE GROWTH CURVES.
C
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
C
C   VARIABLE          MEANING
C
C      B         INTERMEDIATE CONSTANT = 1.0-M OF RICHARDS(1959)
C      D         INTERMEDIATE VARIABLE
C     FRC        FRACTION OF CEILING AVAILABILITY AT WHICH MAX GROWTH RATE OCCUR
C    PASMAX      CEILING YIELDS FOR PASTURE SPECIES
C     PMAX       INTERMEDIATE VARIABLE
C    PMAXGR      MAXIMUM GROWTH RATE OF I-TH SPECIES
C      PRK       RATE CONSTANTS FOR PASTURE SPECIES. EQUIVALENT TO RICHARDS K
C    RICHUD      PARAMETER OF GROWTH EQUATION. EQUIVALENT TO M PARAMETER,RICHARDS
C
      DO 20 J=1,4
      B=1.0-RICHUD(J)
      FRC=RICHUD(J)**(1.0/B)
      PMAX=PASMAX(J)*FRC
      D=PASMAX(J)/PMAX
      D=D**B-1.0
      PRK(J)=PMAXGR(J)*B/PMAX/D
   20 CONTINUE
      RETURN
      END


      FUNCTION FACT(K)
C
C  **  'FACT' EVALUATES FACTORIAL(K)
C
C
C  A FUNCTION SUB-PROGRAM TO EVALUATE FACTORIAL N FROM STIRLINGS
C  FORMULA WITH A LEAT SQUARES FIT TO THE CORRECT (F) AS DESCRIBED IN
C  ABRAMOWITZ AND STEGUN.
C
      DIMENSION FACTSV(8)
      DATA FACTSV/1.,2.,6.,24.,120.,720.,5040.,40320./
      IF(K.LT.9)GOTO 10
      AK=K
      B=2.50662827312*K**(AK+.5)*EXP(-AK)
      F=1.+.083663/(AK+.0015)
      FACT=B*F
      RETURN
   10 FACT=FACTSV(K)
      RETURN
      END
```

```
      SUBROUTINE PASUM
C
C  **  'PASUM' PROVIDES A SUMMARY OF THE INITIAL PASTURE CONDITIONS AND
C      PRINTS OUT SOME OF THE CONSTANTS USED IN THE PROGRAM
C
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(6,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION NCH(4),INTEG(6)
      DIMENSION REPLY(8),ZOUT(20),XOUT(20)
      DATA REPLY/6HCARPET,6H GRASS,6HPASPAL,6HUM    ,6HKIKUYU,6H      ,
     *6HWHITE ,6HCLOVER/
      DATA NCH/10HPADDOCK 1 , 10HPADDOCK 2 ,10HPADDOCK 3 ,10HPADDOCK 4
     *  /
      IF(NPRSUM.EQ.0)RETURN
      WRITE(1,10)
   10 FORMAT(1H1//48X,28H* * * PASTURE  SUMMARY * * *//35X,
     1*TEMPERATURE FUNCTIONS*,10X,*CALCULATED CONSTANTS*//23X,*SPECIES*,
     24X,*COMMENCES  MAXIMIZES  FINISHES     A1        B1        A2        B2*
     3/)
      DO 30 J=1,4
      K=2*J
      L=K-1
      WRITE(1,20)REPLY(L),REPLY(K),(TEMFAC(J,I),I=1,7)
   20 FORMAT(21X,2A6,F8.0,F11.0,F10.0,F11.4,3F8.4)
   30 CONTINUE
   40 FORMAT(  /52X,*INITIAL FERTILITY*
     *//40X,*PADDOCK*,8X,*AREA*,6X,*P FERTILITY   N FERTILITY*/55X,
     *      *(HA)*,9X,*(PPM)*//4(I44,F15.0,I13,F14.2/))
      DO 45 I=1,NPADOK
   45 INTEG(I)=FERTP(I)*20.0+.5
      WRITE(1,40)(I,AREA(I),INTEG(I),FERTN(I),I=1,NPADOK)
      WRITE(1,50)
   50 FORMAT(//49X,*PASTURE GROWTH AND COMPOSITION*// 20X,
     **     SPECIES     VALUE OF    MAX GROWTH RATE   UPPER PARAMETER*, 3X,
     *    *RATE CONSTANT   FRACTION OF UPPER PARAMETER*/ 20X,
     316X,*RICHUD*,6X,*(KG/HA/DAY)*,9X,*(KG/HA)*,
     423X,*AT WHICH MAX GROWTH OCCURS*/)
      DO 70 J=1,4
      FRC=RICHUD(J)**(1.0/(1.0-RICHUD(J)))
      K=2*J
      L=K-1
      WRITE(1,60)REPLY(L),REPLY(K),RICHUD(J),PMAXGR(J),PASMAX(J),PRK(J)
     *           ,FRC
   60 FORMAT(21X,2A6,F8.2,F16.0,F16.0,F20.6,F20.2)
   70 CONTINUE
      WRITE(1,75)
   75 FORMAT(//61X,*INITIAL AVAILABILITY*)
      NLP=1+NPADOK/3
      DO 95 NL=1,NLP
      NN=2
      IF(NPADOK.EQ.1)NN=1
      IF(NPADOK.EQ.3.AND.NL.EQ.2)NN=1
      J=2*NL-1
      K=J+NN-1
      WRITE(1,78)(NCH(I),I=J,K)
```

```
 78 FORMAT(/13X,2(20X,A10,29X))
    WRITE(1,80)((J,J=1,6),K=1,NN)
 80 FORMAT(11X,*COMPONENT*,2(I3,5I7,*    GRD COVER *,2X))
    NCOM=2*NL-1
    DO 95 I=1,4
    J=2*I-1
    K=J+1
    DO 82 L=1,6
 82 INTEG(L)=PLANT(L,I,NCOM)+.5
    WRITE(1,85)REPLY(J),REPLY(K),(INTEG(L),L=1,6),PERCEN(I,NCOM)
 85 FORMAT(1X,2A6,I11,5I7,F9.2)
    IF(NN.NE.2)GO TO 95
    NCOMP=NCOM+1
    DO 88 L=1,6
 88 INTEG(L)=PLANT(L,I,NCOM+1)+.5
    WRITE(1,90)(INTEG(L),L=1,6),PERCEN(I,NCOMP)
 90 FORMAT(1H+,71X,I10,5I7,F10.2)
 95 CONTINUE
    WRITE(1,110)(REPLY(J),J=1,8)
110 FORMAT(//44X,*VALUES FOR FERTF FOR VARYING FN AND FP (PPM)*//
   *     42X,*FN = NITROGEN STATUS (0-1 SCALE, ARBITRARY UNITS)*/
   *     42X,*FP = PHOSPHOROUS STATUS (PPM AVAILABLE PHOSPHOROUS)*//
   *         11X,2A6,21X,2A6,22X,2A6,22X,2A6/)
    DO 120 I=1,5
    A=(I-1)/4.0
    A=A+.000001
    DO 120 J=1,16,5
    ZOUT(I+J-1)=A
120 CONTINUE
    WRITE(1,130)(ZOUT(J),J=1,20)
130 FORMAT(2X,4(*FN*,F6.2,3F5.2,F5.1,5X)/2X,4(*FP*,31X))
    DO 170 I=1,5
    NFP=5*(I-1)
    FP=(I-1)/4.0
    DO 140 J=1,20
    IJ=(J+4)/5
    FN=ZOUT(J)
    CALL SUMREE(IJ,1)
140 XOUT(J)=FERTF
    WRITE(1,150)(NFP,(XOUT(5*J+K-5),K=1,5),J=1,4)
150 FORMAT(1X,4(I3,F6.2,4F5.2,4X))
170 CONTINUE
    RETURN
    END
```

```
      SUBROUTINE ANSUM
C
C  **  THE FUNCTION OF 'ANSUM' IS TO PROVIDE A SUMMARY OF THE ANIMAL PRODUCTIC
C      FUNCTIONS AND THE NUMBERS AND WEIGHTS OF ANIMALS IN EACH RUN.
C
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(5,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      DIMENSION NPT(4),INT(4),NCLASS(12),NT(3),NUMB(4),A(2,6)
      DATA NPT/10HPADDOCK 1 ,10HPADDOCK 2 ,10HPADDOCK 3 ,10HPADDOCK 4 /
     1,NCLASS/10H          ,10H    STEERS,10H    DRY CO,
     210HWS - EMPTY,10H DRY COWS ,10H- PREGNANT,10H LACTNG CO,
     310HWS - EMPTY,10HLACTNG COW,10HS - PREGNT,10H     UNWEA,
     410HNED CALVES /,NT/1HN,10HO   WEIGHT,4H(KG)
      IF(NPRSUM.EQ.0)RETURN                                            /
      WRITE(1,20)(NPT(J),J=1,NPADOK)
   20 FORMAT(1H1//44X,5H* * *,*  SUMMARY OF ANIMAL DATA  *,5H* * *//
     124X,4A20)
      WRITE(1,30)(NT(1),NT(2),J=1,NPADOK)
   30 FORMAT(4X,*NO. *,7X,*CLASS*,7X,4(5X,A1,A10,4X))
      WRITE(1,40)(NT(3),J=1,NPADOK)
   40 FORMAT(28X,4(11X,A4,5X))
      DO 70 I=1,6
      J=2*I
      JJ=J-1
      DO 50 K=1,NPADOK
   50 INT(K)=WT(I,K)+.5
      WRITE(1,60)I,NCLASS(JJ),NCLASS(J),(NOANIM(I,K),INT(K),K=1,NPADOK)
   60 FORMAT(I6,2X,2A10,4(I7,I8,5X))
   70 CONTINUE
      DO 85 I=1,NPADOK
      NUMB(I)=0
      DO 80 J=1,6
   80 NUMB(I)=NUMB(I)+NOANIM(J,I)
   85 WRITE(1,90)(NUMB(J),J=1,NPADOK)
   90 FORMAT(/18X,*TOTAL*,5X,4(I7,13X))
      WRITE(1,110)(I,I=100,600,100),(J,J=100,600,100)
  110 FORMAT( //56X,*CONCEPTION   RATES*//30X,*NON LACTATING COWS*,
     *44X,*LACTATING COWS*/10X,2(* LIVEWT*,15X,*LIVEWEIGHT(KG)*,24X)/10X
     *,2(* CHANGE*,1X,6I7,10X)/10X,* (KG/D)*,51X,*   (KG/D)*)
      DO 160 I=1,5
      WC=(I-3)/2.0
      DO 150 L=1,2
      LL=L-1
      DO 150 J=1,6
      WTT=J*100.
  150 A(L,J)=PREGGO(WTT,WC,LL)
  160 WRITE(1,170)WC,(A(1,K),K=1,6),WC,(A(2,K),K=1,6)
  170 FORMAT(10X,2(F6.1,2X,6F7.2,10X))

      RETURN                                                   2MUSNA LLAC
      ENTRY STAN
      WRITE(1,200)(I,I=1,6)
  200 FORMAT(//10X,*ANIMAL CLASS*,I5,5I7)
      DO 300 N=1,NPADOK
      WRITE(1,210)N
```

```
210 FORMAT(12X,*PADDOCK*,I2)
    DO 300 J=1,6
    IF(NOANIM(J,N).EQ.0)GOTO 300
    NP=7*J+19
    WRITE(1,220)NP,NOANIM(J,N)
220 FORMAT(1H+,I=)
300 CONTINUE
    WRITE(1,230)
230 FORMAT(1H-)
    RETURN
    END
```

```
      SUBROUTINE PLOTIN(MPLOT,KYEAR)
C
C  **  A SUBROUTINE TO 1) DETERMINE THE PLOTS TO BE DONE AND 2) TO ACTUALLY
C       PLOT THE GRAPHS WHEN CALLED THROUGH ENTRY POINT PLOTER
C
      COMMON /CLI/ TEMP,RATIO,WATCAP(2),TOTSM,Z,DL,PRR,RAIN,
     *WP(2),FC(2),FS(2),NSD(2),TRMAX(2),TRR(2),SM(2),HORIZD(2),
     *SUMYR(6),SUMMON(6,12),KPREV,FC1,FS1,WP1,SM1,FC2,FS2,WP2,SM2
      COMMON /PAS/ TEMFAC(4,7),FERTP(4),FERTN(4),FERTAP(4),FERTAN(4),
     *PERCEN(4,4),PLANT(6,4,4),RICHUD(4),PGROTH(4,4),FERTF,
     *FP,FN,DECAY,EVACT,EVPOT,SENESC,SENEST,RESNMX(4),RESPMX(4)
     *,PENMAN,NPADOK,LDAY,PASMAX(4),PRK(4),PMAXGR(4),NPRSUM,LDSV
      COMMON /ANIMAL/ NOANIM(6,4),POTYLD(2,4),YLDMAX(4),BWOOD,
     *CWOOD,NDSUCK(4),NDWEAN(4),NDPREG(4),AWOOD(2,4),GRAIN(4),HAY(4),
     *EMET(6),PASINT(6,4),ACTMLK(2,4),AVWTCH(5,4),FRCINT(6,4),
     *WTAV(6,4,14),WTGAIN(6,4),WT(6,4),AREA(4),LCALL,PTOTAL(4),FIBRE(4),
     *DIGEST(4),AVAILF(4),DIETN(4),ENERGY(4),WTMAX(6,4)
      COMMON /PLOT/NUMPLT(6),NPLOTT(60),AVPGRO(4,4),AVEVAC,AVEVPT,
     *             AVEVRT,AVSAVE(3,4,14),INTPLT,AVSM
      DIMENSION SCALE(44),NIN(10),S(6),TITLE(176),NPLT(10),NPLT1(10),
     *          NPLT2(10),NSOIL(2),FSOIL(2),SOIL(2)
      DATA (TITLE(K),K=1,72)/
     1 10HGREEN LEAF,10H DRY MATTE,10HR (KG/HA) ,10H          ,
     2 10HDRY AND DE,10HAD DRY MAT,10HTER (KG/HA,10H)         ,
     3 10HFLORESCENC,10HE AND SEED,10H DRY MATTE,10HR (KG/HA) ,
     4 10HGROUND COV,10HER OF CARP,10HET GRASS (,10HFRACTION) ,
     5 10HGROUND COV,10HER OF PASP,10HALUM (FRAC,10HTION)     ,
     6 10HGROUND COV,10HER OF KIKU,10HYU (FRACTI,10HON)       ,
     7 10HGROUND COV,10HER OF WHIT,10HE CLOVER (,10HFRACTION) ,
     9 10HCARPET GRA,10HSS AS FRAC,10HTION OF TO,10HTAL DM    ,
     * 10HPASPALUM A,10HS FRACTION,10H OF TOTAL ,10HDM        ,
     2 10HKIKUYU AS ,10HFRACTION O,10HF TOTAL DM,10H          ,
     3 10HWHITE CLOV,10HER AS FRAC,10HTION OF TO,10HTAL DM    ,
     4 10HCARPET GRA,10HSS GROWTH ,10HRATE (KG/H,10HA/DAY)    ,
     5 10HPASPALUM G,10HROWTH RATE,10H (KG/HA/DA,10HY)        ,
     6 10HKIKUYU GRO,10HWTH RATE (,10HKG/HA/DAY),10H          ,
     7 10HWHITE CLOV,10HER GROWTH ,10HRATE(KG/HA,10H/DAY)     ,
     8 10H14-DAY MOV,10HING AVERAG,10HE OF SOIL ,10HMOIST (MM),
     9 10HACTUAL SOI,10HL NITROGEN,10H STATUS   ,10H          ,
     * 10HACTUAL SOI,10HL PHOSPHOR,10HOUS STATUS,10H          /
      DATA (TITLE(K),K=73,112)/
     1 10HACTUAL EVA,10HPOTRANSPIR,10HATION (MM/,10HDAY)      ,
     2 10HPOTENTIAL ,10HEVAPOTRANS,10HPIRATION (,10HMM/DAY)   ,
     3 10HEVAPOTRANS,10HPIRATION R,10HATIO      ,10H          ,
     4 10HCHEWINESS ,10HOF SELECTE,10HD PASTURE ,10H(MIN/KG)  ,
     5 10HMET ENERGY,10H OF SELECT,10HED PASTURE,10H (MCAL/KG),
     6 10HNITROGEN O,10HF SELECTED,10H PASTURE (,10HPERCENT)  ,
     7 10HPASTURE IN,10HTAKE OF ST,10HEERS (KG/D,10HAY)       ,
     8 10HPASTURE IN,10HTAKE OF DR,10HY EMPTY CO,10HWS (KG/D) ,
     9 10HPASTURE IN,10HTAKE OF DR,10HY PREGNT C,10HOWS (KG/D),
     * 10HPASTURE IN,10HTAKE OF LA,10HCT EMPTY C,10HOWS (KG/D)/
      DATA (TITLE(K),K=113,176)/
     1 10HPASTURE IN,10HTAKE OF LA,10HCT PREGT C,10HOWS (KG/D),
     2 10HPASTURE IN,10HTAKE OF CA,10HLVES (KG/D,10HAY)       ,
     3 10H14-DAY AV ,10HWT CHANGE ,10HSTEERS (KG,10H/DAY)     ,
     4 10H14-DAY AV ,10HWT CHANGE ,10HDRY EMPTY ,10HCOW (KG/D),
     5 10H14-DAY AV ,10HWT CHANGE ,10HDRY PREGT ,10HCOW (KG/D),
     6 10H14-DAY AV ,10HWT CHANGE ,10HLAC EMPTY ,10HCOW (KG/D),
     7 10H14-DAY AV ,10HWT CHANGE ,10HLAC PREGT ,10HCOW (KG/D),
     8 10H14-DAY AV ,10HWT CHANGE ,10HCALVES (KG,10H/DAY)     ,
     9 10HWEIGHT OF ,10HSTEERS (KG,10H)         ,10H          ,
     * 10HWEIGHT OF ,10HDRY EMPTY ,10HCOWS (KG) ,10H          ,
```

```
      1 10HWEIGHT OF ,10HDRY PREGNA,10HNT COWS (K,10HG)          ,        39
      2 10HWEIGHT OF ,10HLACTATING ,10HEMPTY COWS,10H (KG)       ,        40
      3 10HWEIGHT OF ,10HLACTATING ,10HPREGNANT C,10HOWS (KG)    ,        41
      4 10HWEIGHT OF ,10HCALVES (KG,10H)          ,10H            ,        42
      5 10HTOTAL PAST,10HURE DRY MA,10HTTER (KG/H,10HA)          ,        43
      6 10HDIGESTIBIL,10HITY OF CON,10HSUMED PAST,10HURE         /        44
       DATA SCALE/2*8000.,2000.,8*1.0,4*200.,300.,2*1.,2*10.,1.,
      *              120.,4.,4.,6*16.,6*4.0,5*1000.,400.,8000.,100./
       DATA NCHAR/10H1234567890/,SOIL/2HWP,2HFC/
       DATA N11/5HGRAPH/,N12/8HVARIABLE/
       DATA (NPLT1(K),K=1,9,2)/5*10H          /,
      1     (NPLT1(K),K=2,8,2)/4*10H         I/,NPLT1(10)/10H          /
       DATA (NPLT2(K),K=1,9,2)/5*10H----------/,
      1     (NPLT2(K),K=2,8,2)/4*10H---------+/,NPLT2(10)/10H---------- /
C
C       SUBROUTINE PLOTIN IS USED IN THE FOLLOWING MANNER
C
C     IF IT IS DESIRED TO PLOT ANY OF THE VARIABLES  IN THE DATA STATEMENTS
C     AT THE COMMENCEMENT TO PLOTIN THEN THE NUMBER ASSOCIATED WITH THAT VARIABLE
C     SHOULD BE ENTERED IN 10I5 FORMAT AS THE LAST CARDS TO BE READ IN TO THE
C     MODEL. ANY OTHER VARIABLES TO BE PLOTTED  ON THE SAME GRAPH ARE ENTERED
C     ON THE SAME CARD.
C     UP TO 6 CARDS CAN BE INSERTED SO THAT UP TO 6 GRAPHS, EACH CONTAINING UP
C     TO 10 PLOTS CAN BE PRODUCED. FURTHER, ONE GRAPH IS PRODUCED FOR EACH
C     PADDOCK SO IF THE MAXIMUM NUMBER OF PADDOCKS ARE USED (4), THEN UP TO
C     24 GRAPHS WILL RESULT. THIS REQUIRES DEFINING UP TO 24 FILES ONTO WHICH
C     THE VARIABLES ARE PLOTTED. THE RELEVANT FILE NUMBERS ONTO WHICH THE GRAPH
C     IS WRITTEN IS DEFINED AS     *PADDOCK NO + CARD NO REQUESTING A PLOT
C         E.G. IF TWO PADDOCKS ARE DEFINED TO EXIST IN ASYSTEM AND TWO CARDS
C     HAVE NUMBERS ON THEM DEFINING THE VARIABLES TO BE PLOTTED THEN
C     THE FILE NUMBERS THAT NEED TO BE DEFINED ARE 11,12,21 AND 22
C
C     AN INITIAL CALL IS MADE TO "PLOTIN". THIS ENABLES THE CARDS TO BE READ
C     AND THE INFORMATION STORED.
C
C     NEXT CALL "HEADPL". THIS RESULTS IN THE HEADING TO EACH GRAPH BEING
C     WRITTEN ONTO THE APPROPRIATE FILE
C     BOTH THESE CALLS ARE MADE WITH PARAMETERS (MPLOT,KYEAR)
C
C     EACH TIME IT IS DESIRED TO PLOT OUT A POINT A CALL TO PLOTER(MPLOT,KYEAR)
C     SHOULD BE MADE. THE VALUE OF KYEAR TOGETHER WITH VARIABLE "LDAY" IS WRITTEN
C     OUT AS WELL.
C
C     IN ORDER TO FINISH THE PLOT OFF WITH A BROKEN LINE AND REINITIALIZE ONE
C     OF THE VARIABLES IN THE ROUTINE, A CALL TO PLOTER(MPLOT,-1) MUST BE MADE
C
       MPLOT=0
       JPL=0
       LDSV=-1
    10 READ(60,20)(NIN(K),K=1,10)
    20 FORMAT(16I5)
       IF(EOF(60)) 90,30
    30 KOUNT=0
    40 KOUNT=KOUNT+1
       IF(NIN(KOUNT).LT.1)GOTO 70
       NPLOTT(JPL+KOUNT)=NIN(KOUNT)
       GOTO 40
    70 JPL=JPL+KOUNT-1
       MPLOT=MPLOT+1
       NUMPLT(MPLOT)=KOUNT-1
       GOTO 10
    90 IF(MPLOT.LE.6)GOTO 110
```

```
      WRITE(6,100)MPLOT
  100 FORMAT(/1X,10(10H**********)/* REQUEST TO PLOT*,I4,* GRAPHS*/
     1    * TOO MANY TO HANDLE, THUS ONLY FIRST 6 REQUESTS ACCEPTED*/
     2    1X,10(10H**********))
      MPLOT=6
  110 RETURN
      ENTRY HEADPL
      IF(MPLOT.EQ.0)RETURN
      DO 280 NPAD=1,NPADOK
      JPL=0
      DO 260 I=1,MPLOT
      LP=I+10*NPAD
      WRITE(LP,105)
  105 FORMAT(1HQ)
      N=NUMPLT(I)
      N1=2
      IF(N.EQ.1)N1=1
      WRITE(LP,120)(N11,N12,KL=1,N1)
  120 FORMAT(/*-PADDOCK*,3X,2(A5,16X,A8,30X))
      WRITE(LP,125)NPAD
  125 FORMAT(I5)
      DO 160 J=1,N,2
      M=NPLOTT(JPL+J)
      JK=LDCH(NCHAR,J)
      IF(J.EQ.N)GOTO 135
      M1=NPLOTT(JPL+J+1)
      JK1=LDCH(NCHAR,J+1)
      GOTO 140
  135 M1=0
  140 MK=4*M-3
      MKP4=MK+3
      M1K=4*M1-3
      M1KP4=M1K+3
      IF(M1.EQ.0)GOTO 150
      WRITE(LP,145)JK,(TITLE(K),K=MK,MKP4),JK1,(TITLE(K),K=M1K,M1KP4)
  145 FORMAT(1H+,12X,R1,6X,4A10,12X,R1,6X,4A10/)
      GOTO 160
  150 WRITE(LP,155)JK,(TITLE(K),K=MK,MKP4)
  155 FORMAT(1H+,12X,R1,6X,4A10/)
  160 CONTINUE
      WRITE(LP,170)
  170 FORMAT(/15X,6(*PLOT SCALE*,10X))
      ISM=0
      DO 200 J=1,N
      M=NPLOTT(JPL+J)
      JK=LDCH(NCHAR,J)
      IF(M.EQ.16)ISM=1
      DO 180 K=1,6
      S(K)=SCALE(M)*(K-1)/5.0
      IF(M.GE.31.AND.M.LE.36)S(K)=S(K)-2.0
  180 CONTINUE
      WRITE(LP,190)(JK,S(K),K=1,6)
  190 FORMAT(15X,6(2X,R1,G11.4,6X))
  200 CONTINUE
      IF(ISM.EQ.0)GOTO 208
      FSOIL(1)=0.0
      FSOIL(2)=0.0
      DO 202 J=1,2
      FSOIL(1)=WP(J)*HORIZD(J)+FSOIL(1)
      FSOIL(2)=FC(J)*HORIZD(J)+FSOIL(2)
  202 CONTINUE
      WRITE(LP,190)
```

```
      DO [illegible] J=1,2
      NSOIL(J)=FSOIL(J)/SCALE(16)*100.0+0.5
      NSOIL(J)=MIN0(100,MAX0(1,NSOIL(J)))
      NPOS=NSOIL(J)+21
      WRITE(LP,207)NPOS,SOIL(J)
  205 CONTINUE
  207 FORMAT(1H+,T=,A2)
  208 WRITE(LP,210)
  210 FORMAT(6X,*DAY*,3X,*YEAR*,4X,5(*+-------------------*),*-+*)
      JPL=JPL+N
  280 CONTINUE
      RETURN
      ENTRY PLOTER
      IF(MPLOT.EQ.0)RETURN
      DO 500 NPAD=1,NPADOK
      JPL=0
      DO 500 N=1,MPLOT
      LP=N+10*NPAD
      IF(KYEAR.LT.1)GOTO 510
      NN=NUMPLT(N)
      DO 300 I=1,10
      IF(LDAY.LT.LDSV.AND.KYEAR.NE.1)GOTO 305
      NPLT(I)=NPLT1(I)
      GOTO 300
  305 NPLT(I)=NPLT2(I)
  300 CONTINUE
      MZ=LDCH(NPLT,20)
      ISM=0
      DO 460 IJ=1,NN
      M=NPLOTT(IJ+JPL)
      GOTO(315,320,325,330,330,330,330,335,335,335,335,340,340,340,340,
     *      345,350,355,360,365,370,375,380,385,390,390,390,390,390,390,
     *      395,395,395,395,395,395,400,400,400,400,400,400,405,415),M
  315 P=0.0
      DO 318 I=1,4
      DO 318 J=1,4
  318 P=P+PLANT(J,I,NPAD)*PERCEN(I,NPAD)
      GOTO 410
  320 P=0.0
      DO 322 I=1,4
  322 P=P+PLANT(5,I,NPAD)*PERCEN(I,NPAD)
      GOTO 410
  325 P=0.0
      DO 328 I=1,2
  328 P=P+PLANT(6,I,NPAD)*PERCEN(I,NPAD)
      GOTO 410
  330 P=PERCEN(M-3,NPAD)
      GOTO 410
  335 P=PTOTAL(NPAD)
      Q=0.0
      DO 339 J=1,6
  339 Q=Q+PLANT(J,M-7,NPAD)*PERCEN(M-7,NPAD)
      P=Q/P
      GOTO 410
  340 P=AVPGRO(M-11,NPAD)
      GOTO 410
  345 P=AVSM
      ISM=1
      GOTO 410
  350 P=FERTAN(NPAD)
      GOTO 410
  355 P=FERTAP(NPAD)
```

```
      GOTO 410
  360 P=AVEVAC
      GOTO 410
  365 P=AVEVPT
      GOTO 410
  370 P=AVEVRT
      GOTO 410
  375 P=FIBRE(NPAD)
      GOTO 410
  380 P=ENERGY(NPAD)
      GOTO 410
  385 P=DIETN(NPAD)
      GOTO 410
  390 P=PASINT(M-24,NPAD)
      GOTO 410
  395 P=AVWTCH(M-30,NPAD)+2.0
      GOTO 410
  400 P=WT(M-36,NPAD)
      GOTO 410
  405 P=PTOTAL(NPAD)
      GOTO 410
  415 P=DIGEST(NPAD)*100.
  410 NPOS=P/SCALE(M)*100.+.5
      NPOS=MIN0(100,MAX0(1,NPOS))
      K=LDCH(NCHAR,IJ)
      CALL STCH(NPLT,NPOS,K)
  460 CONTINUE
      IF(ISM.EQ.0)GOTO 478
      DO 475 I=1,2
      K=LDCH(NPLT,NSOIL(I))
      IF(K.NE.1R )GOTO 475
      CALL STCH(NPLT,NSOIL(I),1R,)
  475 CONTINUE
  478 JPL=JPL+NN
  470 FORMAT(I9,I6,5X,R1,10A10,R1)
      WRITE(LP,470)LDAY,KYEAR,MZ,(NPLT(K),K=1,10),MZ
      GOTO 500
  510 WRITE(LP,480)
  480 FORMAT(20X,5(*+------------------*),*-+*)
      IF(KYEAR.LT.1)LDSV=-1
  500 CONTINUE
      LDSV=LDAY
      RETURN
      END
```